

Fig. 1

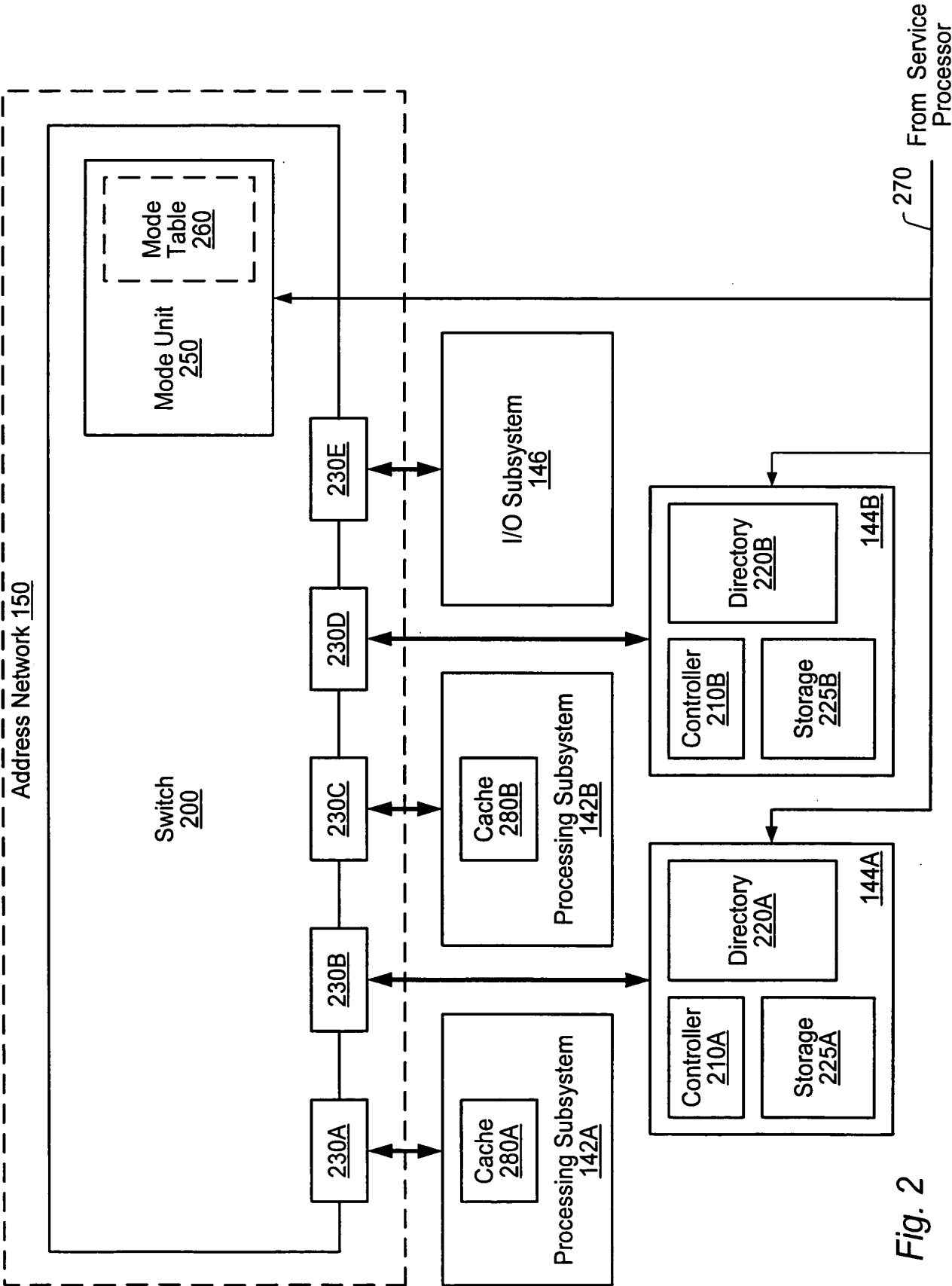


Fig. 2

260

| | Address Range <u>502</u> | Home <u>504</u> | Mode <u>506</u> |
|------|-----------------------------|--------------------|--------------------|
| 510A | A | Client 3 | PTP |
| 510B | B | Client 3 | BC |
| 510C | C | Client 1 | PTP |
| 510D | D | Client 4 | PTP |
| 510E | E | Client 3 | BC |
| 510F | F | Client 2 | BC |
| 510G | G | Client 5 | PTP |
| | . | . | . |
| | . | . | . |
| | . | . | . |

Fig. 3

220A

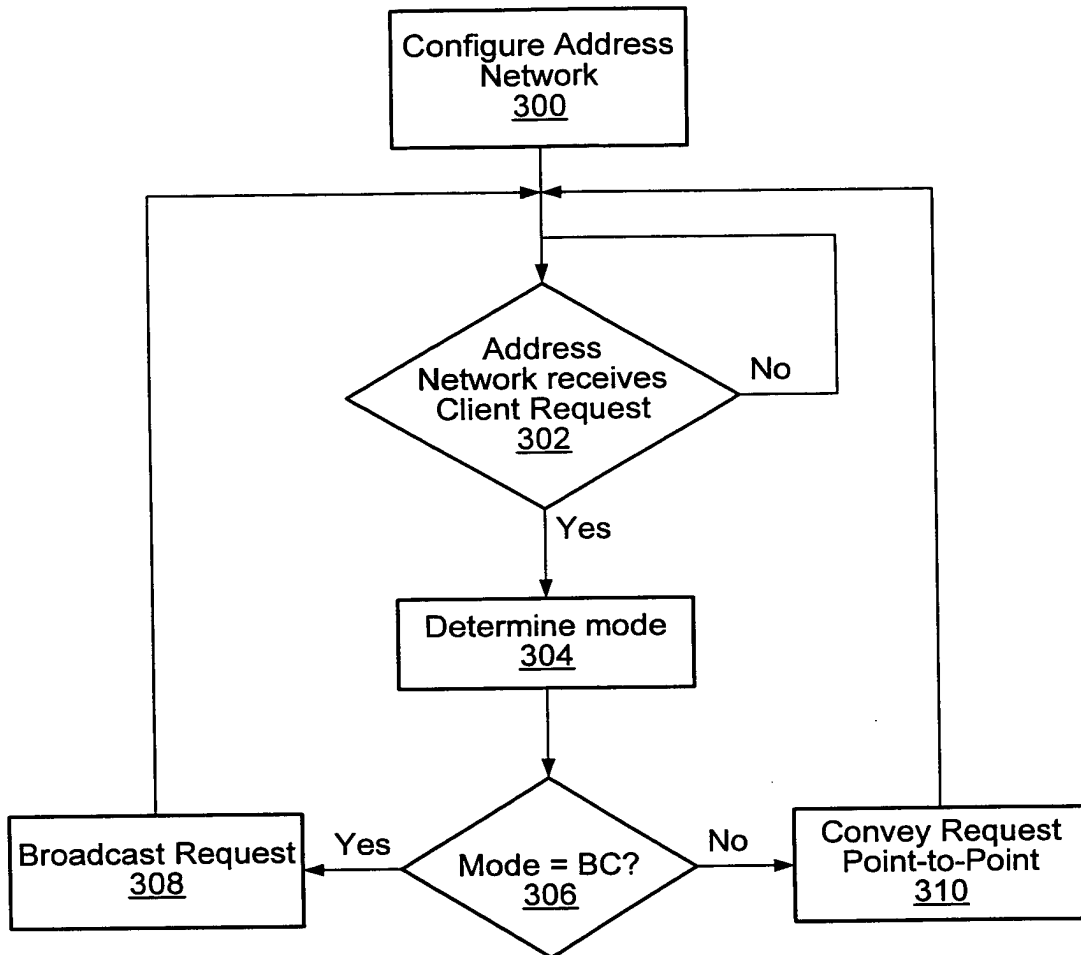
| Address 602 | Client 1 604 | Client 2 606 | Client 3 608 | Client 4 610 | Client 5 612 | Owner 614 |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--------------|
| Aa | I | I | M | I | I | Client 3 |
| Ab | I | I | M | I | I | Client 3 |
| Ac | I | I | M | I | I | Client 3 |
| Ad | O | I | S | S | I | Client 1 |
| Ae | S | I | S | S | I | None |
| Af | S | I | O | I | I | Client 3 |
| Ag | I | I | I | M | I | Client 4 |
| . | . | . | . | . | . | . |
| . | . | . | . | . | . | . |
| . | . | . | . | . | . | . |

Fig. 4

220B

| | Address 602 | Client 1 604 | Client 2 606 | Client 3 608 | Client 4 610 | Client 5 612 | Owner 614 |
|------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--------------|
| 620A | Aa | I | I | W | I | I | Client 3 |
| 620B | Ab | I | I | W | I | I | Client 3 |
| 620C | Ac | I | I | W | I | I | Client 3 |
| 620D | Ad | R | I | R | R | I | Client 1 |
| 620E | Ae | R | I | R | R | I | None |
| 620F | Af | R | I | R | I | I | Client 3 |
| 620G | Ag | I | I | I | W | I | Client 4 |
| | . | . | . | . | . | . | . |
| | . | . | . | . | . | . | . |
| | . | . | . | . | . | . | . |

Fig. 4A

*Fig. 5*

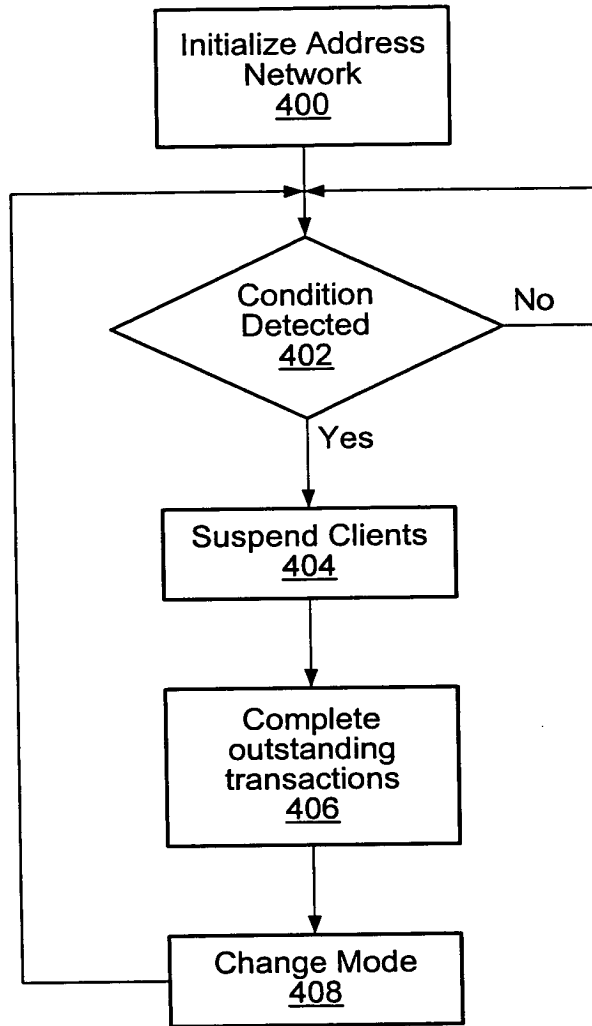


Fig. 6

| Packet Type | Full Name | Address Space | | Description |
|-------------|-----------------|---------------|-----|--|
| | | Cacheable | I/O | |
| RTS | ReadToShare | Y | | Requests read-only copy of cache line |
| RTO | ReadToOwn | Y | | Requests writable copy of cache line |
| RTWB | ReadToWriteBack | Y | | Requests to receive writable copy of cache line and send cache line to memory |
| RS | ReadStream | Y | | Request read-once copy of cache line |
| WS | WriteStream | Y | | Request to write entire cache line and send to memory |
| WB | WriteBack | Y | | Request to send cache line from owning device to memory, device does not keep copy |
| WBS | WriteBackShared | Y | | Request to send cache line from owning device to memory, device keeps read-only copy |
| RIO | ReadIO | | Y | Request to read IO locations |
| WIO | WriteIO | | Y | Request to write IO locations |
| INT | Interrupt | | | Sends an interrupt, target is specified by address |

Fig. 7

| Transaction Type | Initiator Receives | Initiator Sends |
|------------------|--------------------|-----------------|
| RTS | DATA | |
| RTO | DATA | |
| RTWB | DATA & PRN | DATA |
| RS | DATA | |
| WS | ACK & PRN | DATA |
| WB | PRN | DATA or NACK |
| WBS | PRN | DATA or NACK |

Fig. 8

| Transaction Type | Initiator Receives | Initiator Sends |
|------------------|--------------------|-----------------|
| RIO | DATA | |
| WIO | PRN | DATA |
| INT | PRN or NACK | DATA or Nothing |

Fig. 9

| Access Rights Symbol | Access Rights Name | Description | Data Present? |
|----------------------|--------------------|--|---------------|
| W | Write | Read and Write | Yes |
| A | All-Write | Write-only, must write entire cache line | Yes (or ACK) |
| R | Read | Read-only | Yes |
| T | Transient-Read | Read-only, read can be reordered | Yes |
| I | Invalid | No access rights | Yes or No |

Fig. 10A

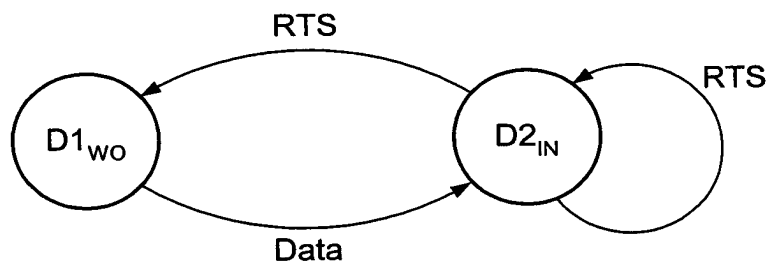
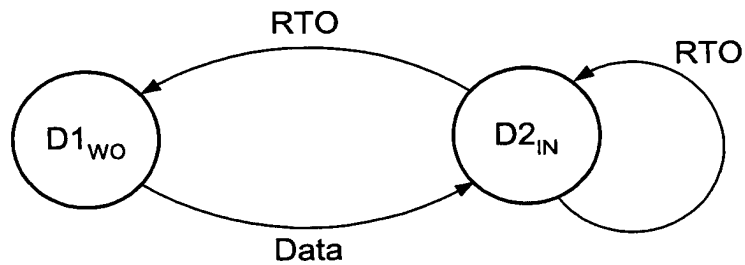
| Ownership Status Symbol | Ownership Status Name | Description | Data Present? |
|-------------------------|-----------------------|-------------------------|---------------|
| O | Owner | Owens cache line | Yes or No |
| N | Not Owner | Does not own cache line | Yes or No |

Fig. 10B

| Access Right | Ownership Status |
|--------------|------------------|
| W | O |
| R | O |
| I | O |
| W | N |
| A | N |
| R | N |
| T | N |
| I | N |

Fig. 10C

| Transaction Type | New Owner |
|------------------|----------------------------|
| RTS | Previous Owner |
| RTO | Initiator |
| RTWB | Memory |
| RS | Previous Owner |
| WS | Memory |
| WB | Memory (or Previous Owner) |
| WBS | Memory (or Previous Owner) |

Fig. 11*Fig. 12A**Fig. 12B*

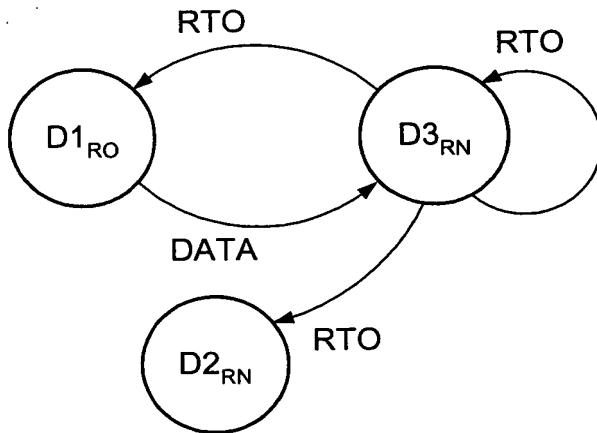


Fig. 12C

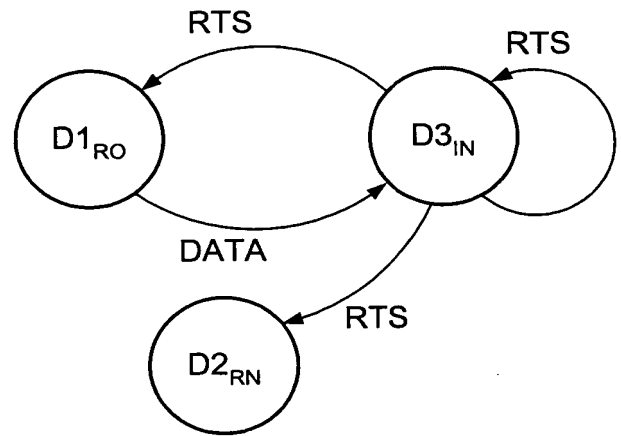


Fig. 12D

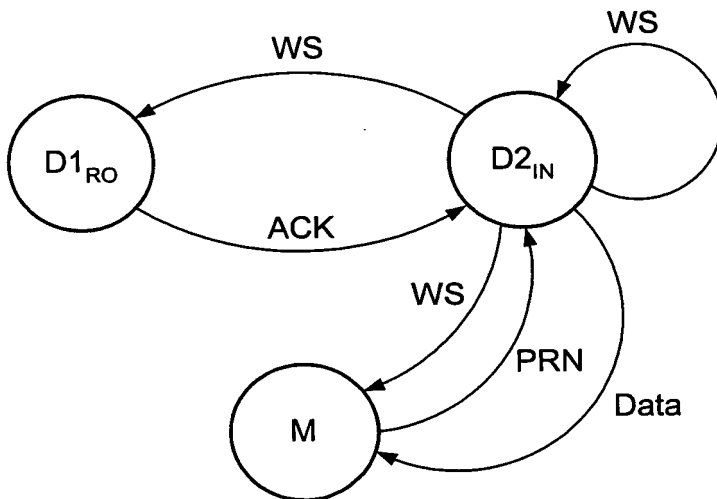


Fig. 12E

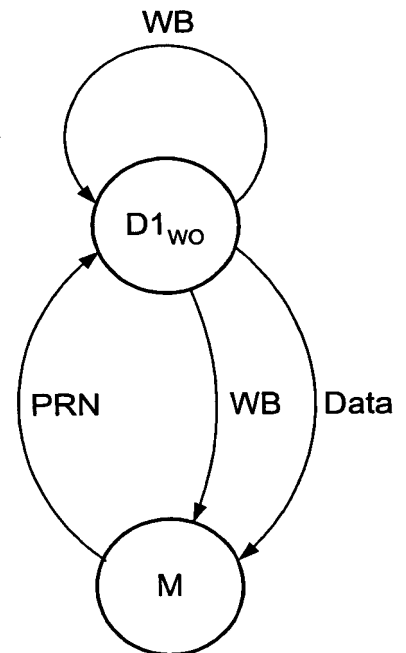
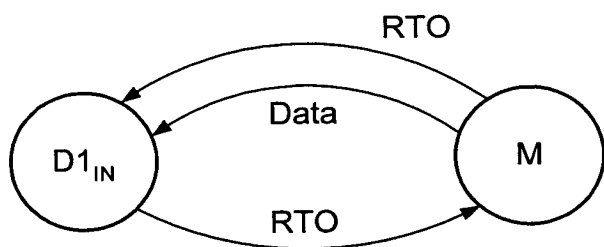
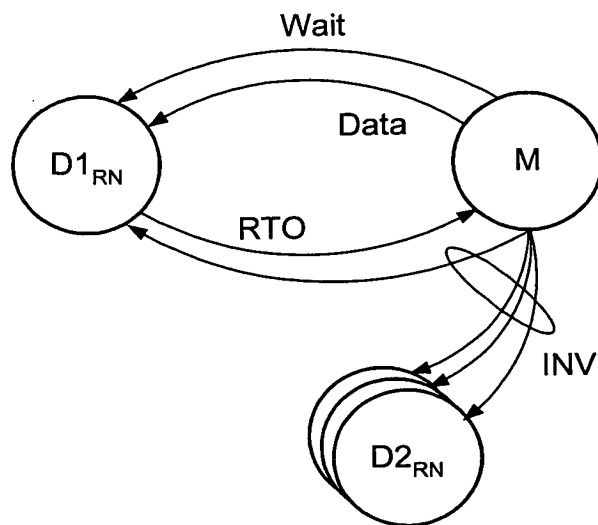
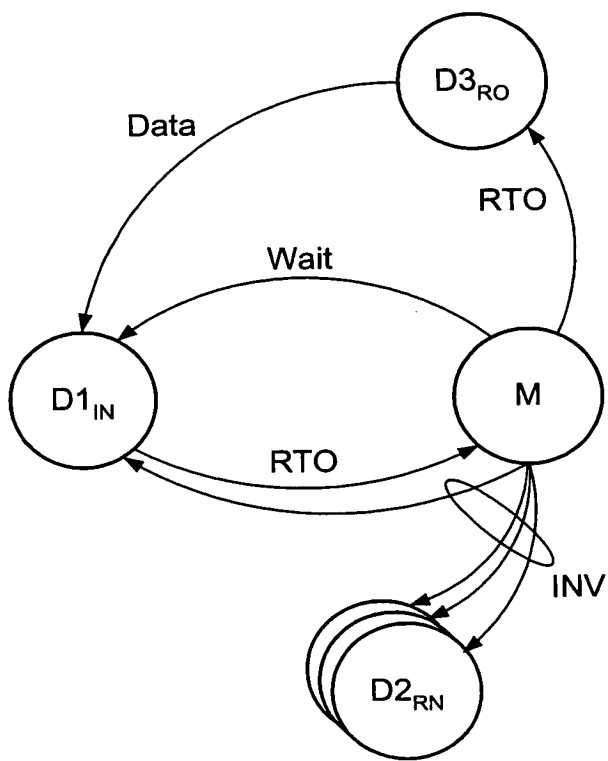
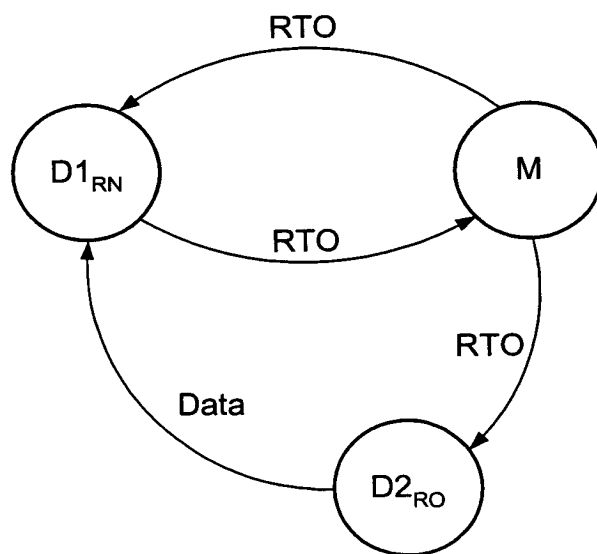


Fig. 12F

*Fig. 13A**Fig. 13B**Fig. 13C**Fig. 13D*

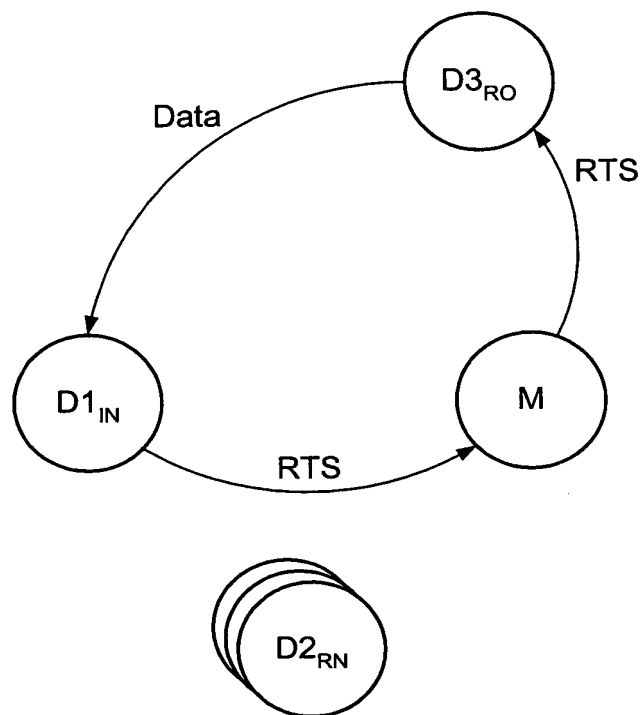


Fig. 13E

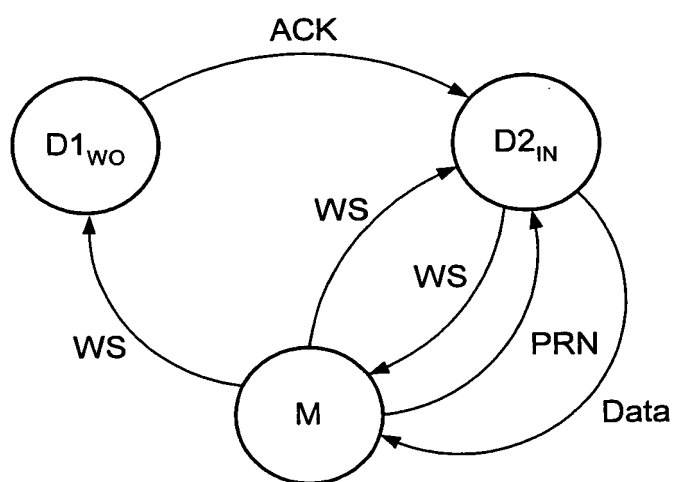


Fig. 13F

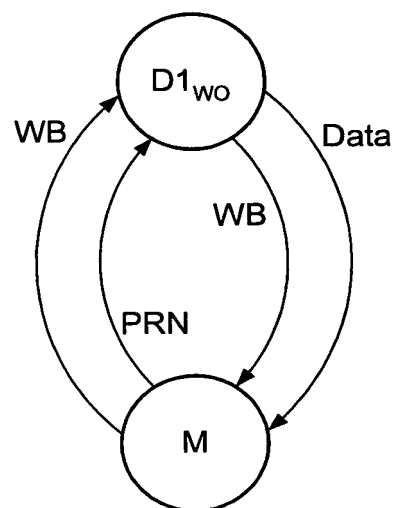


Fig. 13G

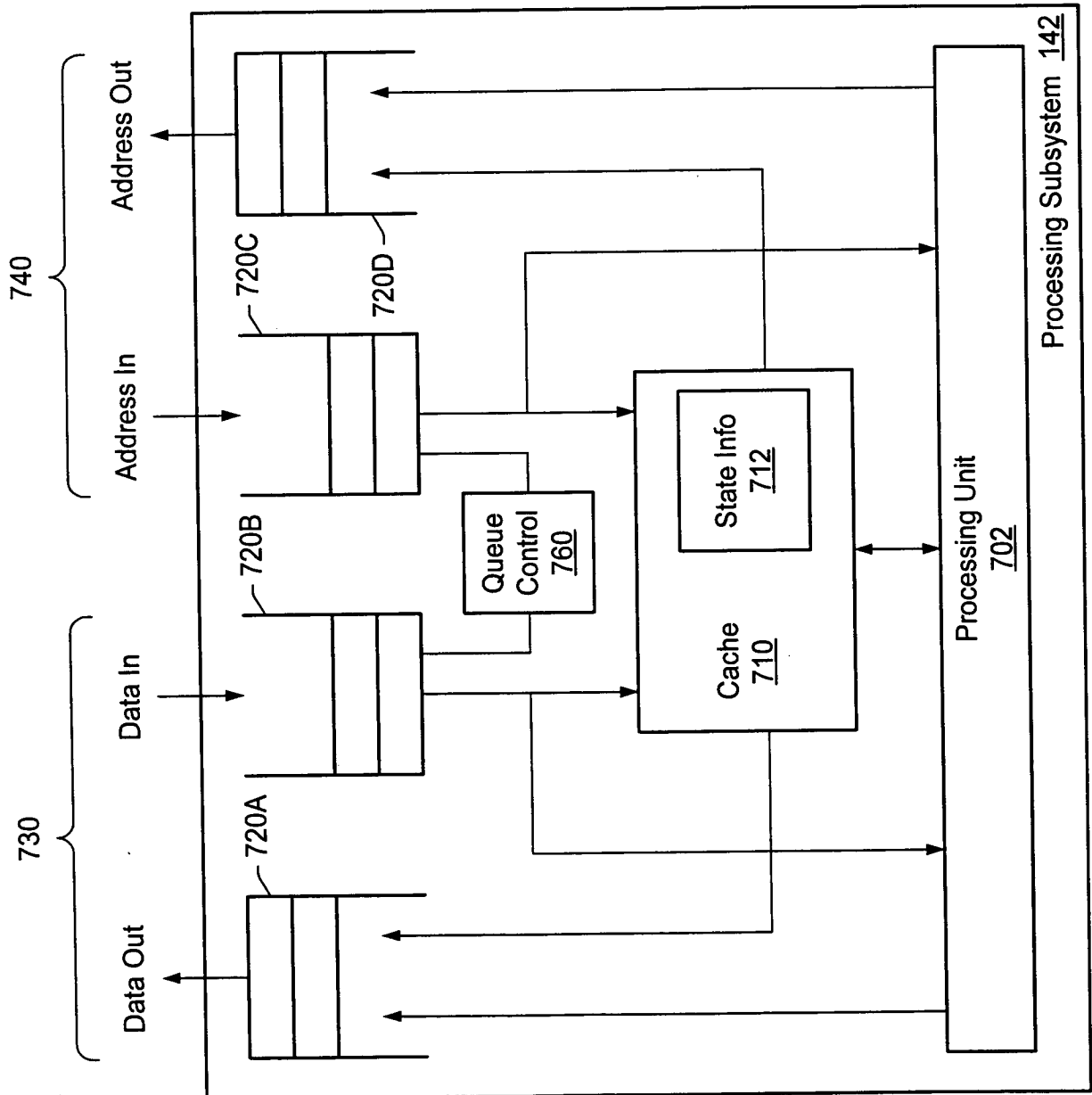
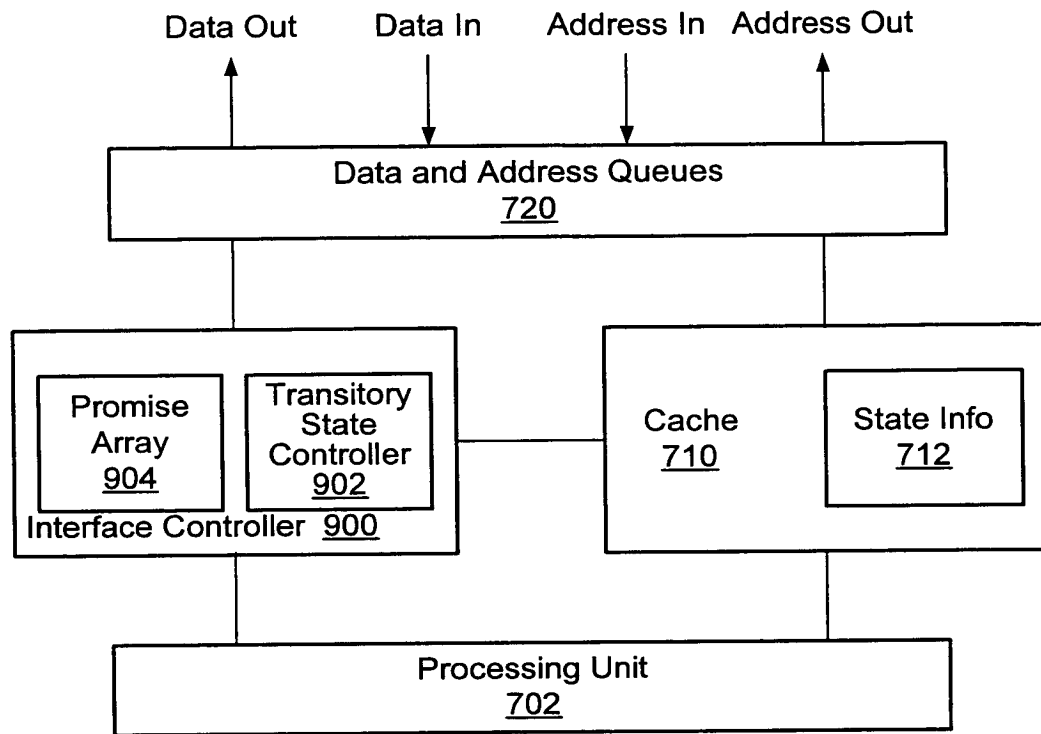


Fig. 14

*Fig. 15*

| StateDescription | |
|------------------|--|
| WO _{fh} | Waiting for WAIT and ACK for local WS, has write access and ownership |
| WO | Stable state with write access and ownership |
| RO _{fh} | Waiting for WAIT and ACK for local WS, has read access and ownership |
| RO _e | Waiting for DATA for local RTO, has read access and ownership |
| RO _{de} | Waiting for INV and DATA for local RTO, has read access and ownership |
| RO _d | Waiting for INV for local RTO, has read access and ownership |
| RO _{ce} | Waiting for WAIT and DATA for local RTO, has read access and ownership |
| RO | Stable state with read access and ownership |
| IO _e | Waiting for DATA for local RTO, has no access rights, has ownership |
| IO _{de} | Waiting for INV and DATA for local RTO, has no access rights, has ownership |
| IO _d | Waiting for INV for local RTO, has no access rights, has ownership |
| WN _j | Able to send DATA/NACK for local WB/WBS, has write access and no ownership |
| WN _i | Able to send DATA for local RTWB, write access, no ownership |
| WN _h | Waiting for ACK for local WS, has write access, no ownership |
| WN _e | Waiting for WAIT for local RTO, has write access, no ownership |
| WN | Stable state with write access, no ownership (caused by foreign transaction that took ownership, but for which no copyback has yet been performed) |
| AN _i | Able to send DATA for local WS after performing write to entire cache line, no ownership |
| RN _j | Able to send DATA/NACK for local WB/WBS, has read access and no ownership |
| RN _h | Waiting for ACK for local WS, has read access, no ownership |
| RN _g | Waiting for INV for local WS, has read access, no ownership |
| RN _e | Waiting for DATA for local RTO, has read access, no ownership |
| RN _{de} | Waiting for INV and DATA for local RTO, has read access, no ownership |
| RN _d | Waiting for INV for local RTO, has read access, no ownership |
| RN _{ce} | Waiting for WAIT and DATA for local RTO, has read access, no ownership |
| RN _{cd} | Waiting for WAIT and INV for local RTO, has read access, no ownership |
| RN | Stable state with read access, no ownership |
| TN | Performing read(s), which may be reordered, for local RTS or RS, no ownership |
| IN _k | Waiting for RTO, RTWB, WS, WB or WBS after receiving an ERR or ERRL. No access rights, no ownership |
| IN _j | Able to send DATA/NACK for local WB/WBS, has no access and no ownership |
| IN _h | Waiting for ACK for local WS or for DATA for local RTWB, has no access rights, no ownership |
| IN _g | Waiting for INV for local WS or for INV for local RTWB, has no access rights, no ownership |
| IN _e | Waiting for DATA for local RTO, has no access rights, no ownership |
| IN _{de} | Waiting for INV and DATA for local RTO, has no access rights, no ownership |
| IN _d | Waiting for INV for local RTO, has no access rights, no ownership |
| IN _{ce} | Waiting for WAIT and DATA for local RTO, has no access rights, no ownership |
| IN _{cd} | Waiting for WAIT and INV for local RTO, has no access rights, no ownership |
| IN _a | Waiting for DATA for local RTS, DATA may grant read access, has no access rights, no ownership |
| IN | Stable state with no access rights, no ownership |

Fig. 15A

| Action Code | Meaning | Comments |
|-------------|--|---|
| /a | Commit to send an ACK packet as a copyback by appending an entry for the received foreign packet in a copyback list. Set copy tag to I. | ACK packet may be sent from any state that allows copyback packets to be sent. It must be sent within a finite time of first entering such a state, regardless of what other packets have been received. |
| c/ | Commit to send DATA and/or ACK packets for all outstanding copybacks for this cache line. Next, set copy tag to W. Then, perform state transition based on current state & local packet being received | If sending copybacks changes the state from a state X to a state Y, the local packet being received will be received in state Y (and as a result, the entry for state Y in the table must be consulted to determine the state transition caused by receiving the local packet). |
| /d | Commit to send DATA packet for local RTWB, WS, WB, or WBS transaction. DATA packet is sent in response to receiving a PRN packet for this transaction. | DATA packet may not be sent until a PRN packet is received. It must be sent within finite time of receiving the PRN packet & having entered a state that permits the packet to be sent, regardless of what other packets have been received. |
| e/ | Clear outstanding copyback commitments for this line by removing them from the copyback list. Do not send DATA or ACK packets for entries that were on the copyback list. Next, perform state transition based on current state & local packet being received. | The action code is used in response to receiving an ERR or ERRL packet. If an ERR packet was received in place of a PR or PRACK packet, or if an ERRL packet was received in place of a DATAP packet, a DATA packet may be sent to the error device. |
| /i | Commit to send a DATA packet as a copyback by appending an entry for the received foreign packet in the copyback list. Set copy tag to I. | DATA packet may be sent from any state that allows copyback packets to be sent. It must be sent within finite time of first entering such a state, regardless of what other packets have been received. |
| /j | Set write tag to I. | |
| /n | Commit to send NACK packet for local WB or WBS transaction & set write tag to W. NACK packet is sent in response to receiving a PRN packet for this transaction. | NACK packet may be sent at any time after receiving the PRN packet. It must be sent within finite time of receiving the PRN packet, regardless of what other packets have been received. |
| /r | Commit to send DATA packet as a copyback by appending an entry for the received foreign packet in the copyback list. If copy tag is W, set copy tag to R. | DATA packet may be sent from any state that allows copyback packets to be sent. It must be sent within finite time of first entering such a state, regardless of what other packets have been received. |
| /s | Set write tag to R. | |
| /w | Commit to send DATA packet as a copyback by appending an entry for the received foreign packet in the copyback list. | DATA packet may be sent from any state that allows copyback packets to be sent. It must be sent within finite time of first entering such a state, regardless of what other packets have been received. |
| /y | If copy tag is R, set copy to I. | Used to record invalidating transactions while a copyback for a foreign memory remap is pending. |
| /z | If write tag is R, set write to I. | Used to record invalidating transactions while a local WBS transaction is pending. |

Fig. 15B

Fig. 15C

| Send on Address Network | | Receive | | Send DATA or NACK | | Silent Downgrade | |
|-------------------------|------------------|---------|--|-------------------|--|------------------|--|
| RTS (a) | | | | | | | |
| RS | | | | | | | |
| RTO | | | | | | | |
| RTWB | | | | | | | |
| WS/WB | \overline{I}/I | | | | | | |
| WBS | \overline{I}/I | | | | | | |
| DATA for RTS | | | | | | | |
| DATA for RS | | | | | | | |
| RTO (c+d) | | | | | | | |
| WAIT for RTO (c) | | | | | | | |
| INV for RTO (d) | | | | | | | |
| DATA for RTO (e) | | | | | | | |
| RTWB/INV for RTWB (g) | | | | | | | |
| DATA for RTWB (h) | | | | | | | |
| WS (f+g) | | | | | | | |
| WAIT for WS (f) | | | | | | | |
| INV for WS (g) | | | | | | | |
| ACK for WS (h) | | | | | | | |
| WB/WBS | | | | | | | |
| ERR (2) | | | | | | | |
| ERRL for RTS/RS | | | | | | | |
| ERRL for RTO/RTWB (2) | | | | | | | |
| Write tag W | | | | | | | |
| Write tag R | | | | | | | |
| Write tag I | | | | | | | |

REPLACEMENT SHEET

20 / 43

| Old State | Receive | | | | | | | Send DATA or ACK copyback packet | | |
|------------------|---------|-----|---------------------|---------------------|------------------|--------------------|--------------------|-------------------------------------|------------------|------------------|
| | RS | RTS | RTD/ RTWB | WS | INV | MRM | MDM | Copy tag W | Copy tag R | Copy tag I |
| WO _{fh} | /w | /r | WN _h /i | WN _h /a | | | | | RO _{fh} | |
| WO | /w | /r | WN _i | WN _a | /z | WN _r | WN _i | | RO | |
| RO _{fh} | /w | /r | RN _h /i | RN _h /a | | | | | | |
| RO _e | /w | /r | RN _e /i | RN _e /a | IO _e | RN _e /r | RN _e /i | | | |
| RO _d | /w | /r | RN _d /i | RN _d /a | IO _d | | | | | |
| RO _d | /w | /r | RN _d /i | RN _d /a | | | | | | |
| RO _{ce} | /w | /r | RN _{ce} /i | RN _{ce} /a | | | | | | |
| RO | /w | /r | RN _i | RN _a | /z | RN _r | RN _i | | | |
| IO _e | /w | /r | IN _e /i | IN _e /a | | IN _e /r | IN _e /i | | | |
| IO _d | /w | /r | IN _d /i | IN _d /a | | | | | | |
| IO _d | /w | /r | IN _d /i | IN _d /a | | | | | | |
| WNI | | | | | | | | | | |
| WN _h | | | | | | | | | RN _h | IN _h |
| WN _c | | | | | | | | | | |
| WN _j | | | /yz | /yz | /z | | /yz | | RN _j | IN _j |
| WN | | | /y | /y | /z | | /y | | RN | IN |
| AN _i | | | | | | | | | | |
| RN _h | | | | | IN _h | | | | | IN _h |
| RN _g | | | | | | | | | | |
| RN _e | | | /y | /y | IN _e | | /y | | | |
| RN _d | | | | | IN _d | | | | | |
| RN _d | | | | | | | | | | |
| RN _{ce} | | | | | IN _{ce} | | | | | IN _{ce} |
| RN _{cd} | | | | | | | | | | |
| RN _j | | | IN _j | IN _j | IN _j | | IN _j | | | IN _j |
| RN | | | IN | IN | IN | | IN | | | IN |
| TN | | | | | | | | | | |
| IN _h | | | | | | | | | | |
| IN _g | | | | | | | | | | |
| IN _e | | | /y | /y | | | /y | | | |
| IN _d | | | | | | | | | | |
| IN _d | | | | | | | | | | |
| IN _{ce} | | | | | | | | | | |
| IN _{cd} | | | | | | | | | | |
| IN _k | | | | | | | | | | |
| IN _j | | | | | | | | | | |
| IN _a | | | IN | IN | IN | | IN | | | |
| IN | | | | | | | | | | |

Fig. 15D

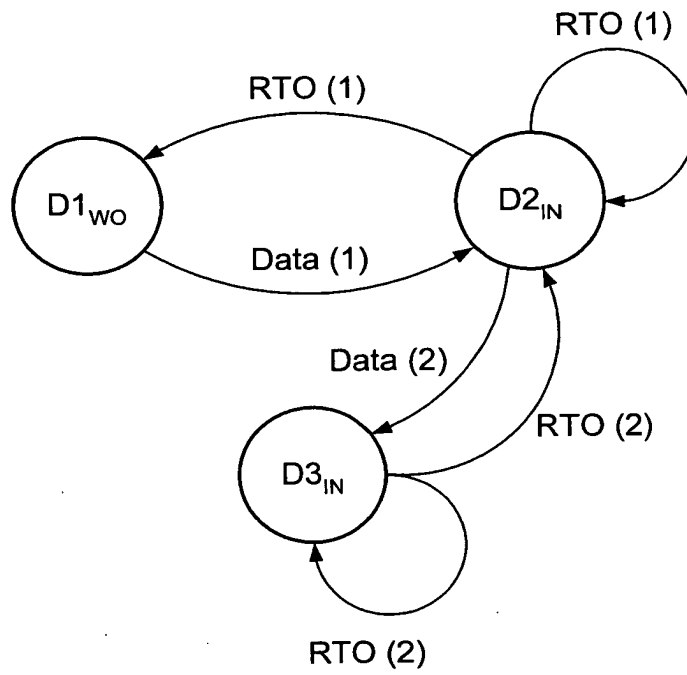


Fig. 16

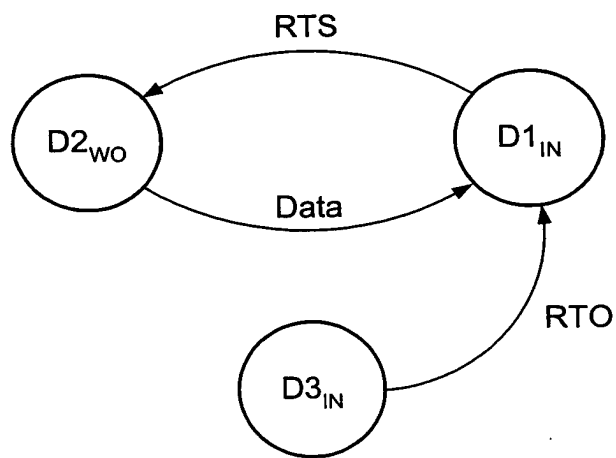


Fig. 17

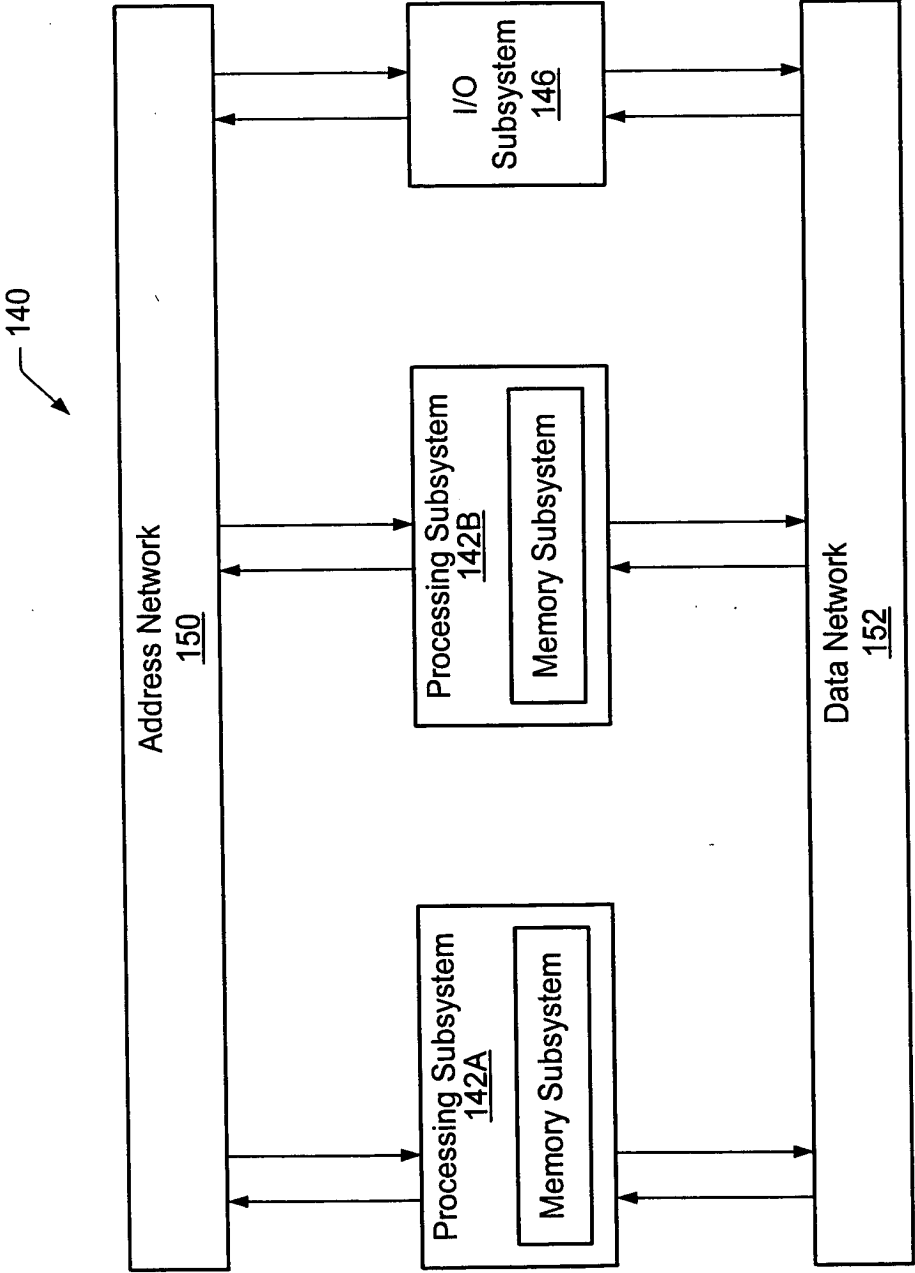


Fig. 18

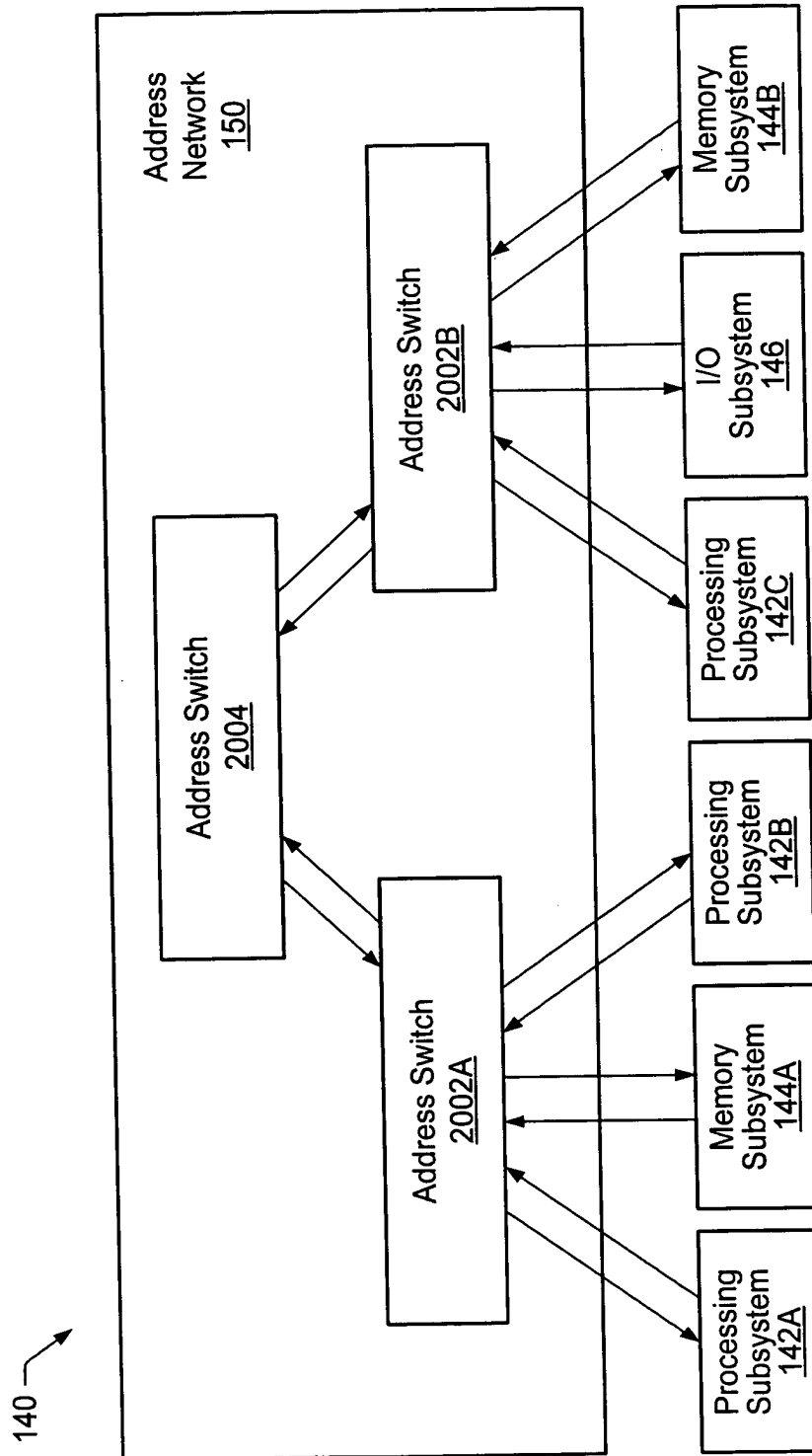


Fig. 19

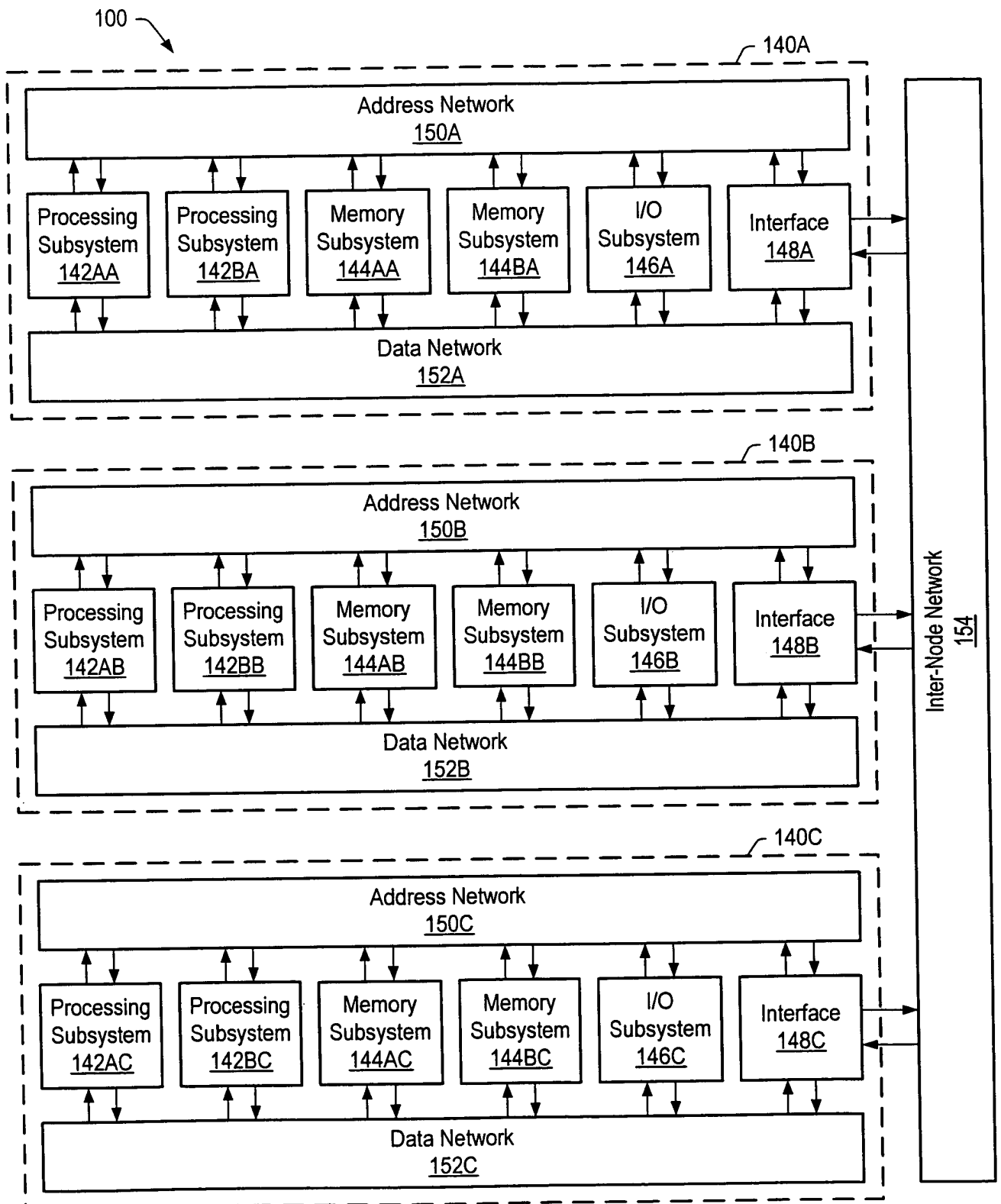


Fig. 20

| gTag | Description |
|-------------|--|
| gM | The maximum access right within the node is Write Access |
| gS | The maximum access right within the node is Read Access. No client device in the node can have Write Access. |
| gI | The maximum access right within the node is Invalid Access. No client device in the node can have Read or Write Access. |

Fig. 21

| Packet Type | Full Name | Address Space | | Description |
|-------------|---------------------------|---------------|-----|--|
| | | Cacheable | I/O | |
| PRTS | Proxy RTS | Y | | Request from an interface in a gS or gi node in response to a RTS request from another node |
| PRTSM | Proxy RTS Modified | Y | | Request from an interface in a gM node in response to a RTS request from another node |
| PRTOM | Proxy RTO Modified | Y | | Request from an interface in a gM node in response to a RTO request from another node |
| PRTO | Proxy ReadToOwn | Y | | Request from an interface in response to a RTO request from another node |
| PU | Proxy Upgrade | Y | | Request from an interface asking memory to supply data for an outstanding RTO |
| PDU | ProxyDataUpgrade | Y | | Request from an interface asking memory to update gTag to gM; interface supplies data for an outstanding RTO |
| PRSM | Proxy ReadStream Modified | Y | | Request from an interface in a gM node in response to RS request from another node |
| PIM | ProxyInvalidate Modified | Y | | Request from an interface in a gM node to invalidate data in caches and memory |
| PI | ProxyInvalidate | Y | | Request from an interface in a gS or gl node to invalidate data in caches and memory |
| PMR | ProxyMemoryRead | Y | | Request from an interface to memory to read coherency state(s) and data or meta-data |
| PMW | ProxyMemoryWrite | Y | | Request from an interface to memory to write coherency state(s) and data or meta-data |

Fig. 22

| Packet Type | Full Name | Description |
|-------------|-------------|--|
| DATAM | Data-Meta | Data packet containing data and coherence state information |
| DATAN | Data-NoPull | Data packet sent in response to PRTSM indicating no PRN will be coming |
| REP | Report | Report from memory to an interface indicating a transaction to be handled by the interface |

Fig. 23

| Subtransaction | Preexisting Global Access State | New Global Access State |
|----------------|---------------------------------|--|
| PRTSM | Modified | Shared |
| PRTOM | Modified | Invalid |
| PRT0 | Shared, Invalid | Invalid |
| PU | Shared | Modified |
| PDU | Shared, Invalid, Modified | Modified |
| PRSM | Modified | Unchanged |
| PIM | Modified | Invalid |
| PI | Shared, Invalid | Invalid |
| PMR | Shared, Invalid, Modified | Unchanged |
| PMW | Shared, Invalid, Modified | Equal to new global access state specified in DATAM packet |

Fig. 24

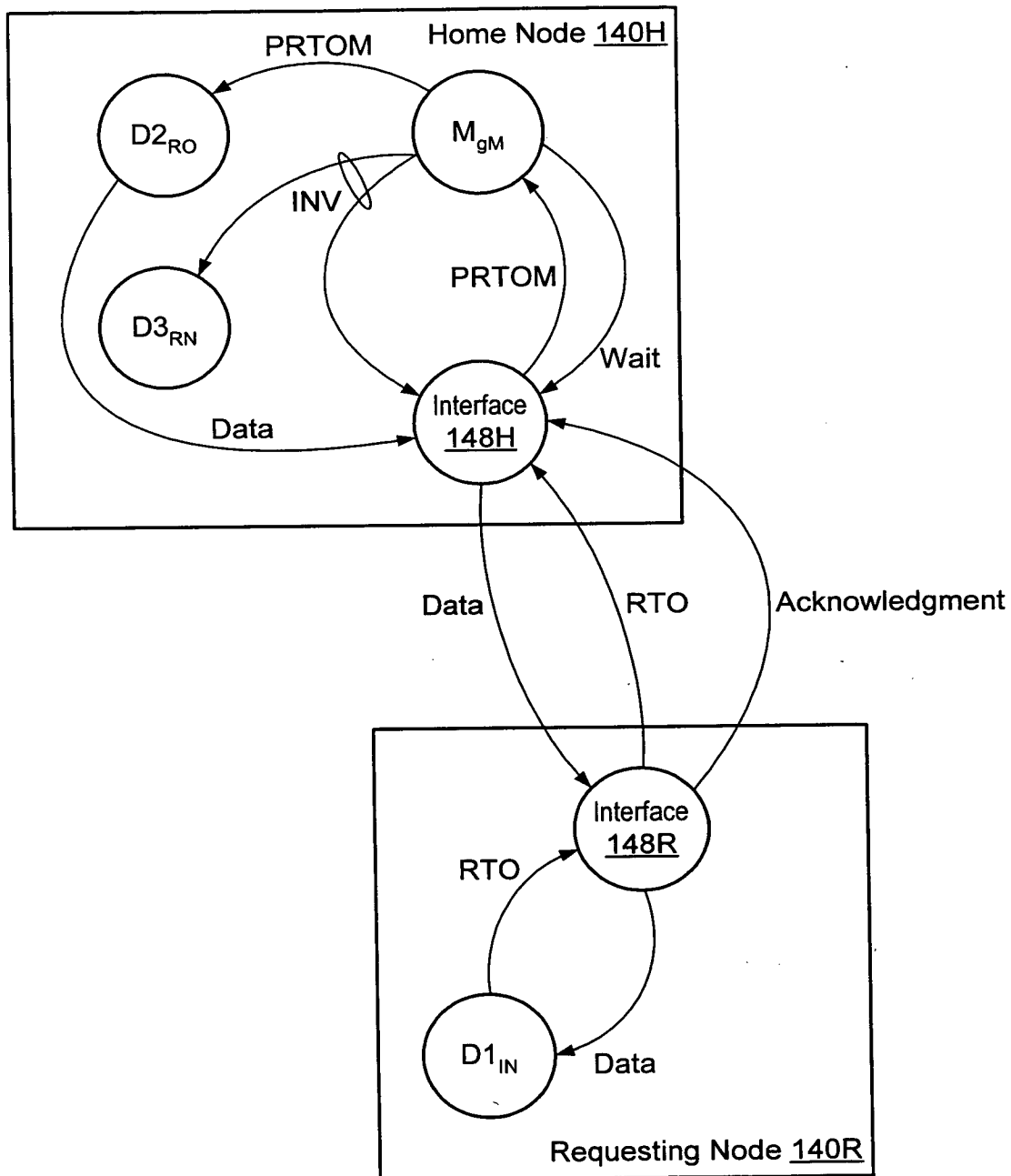


Fig. 25

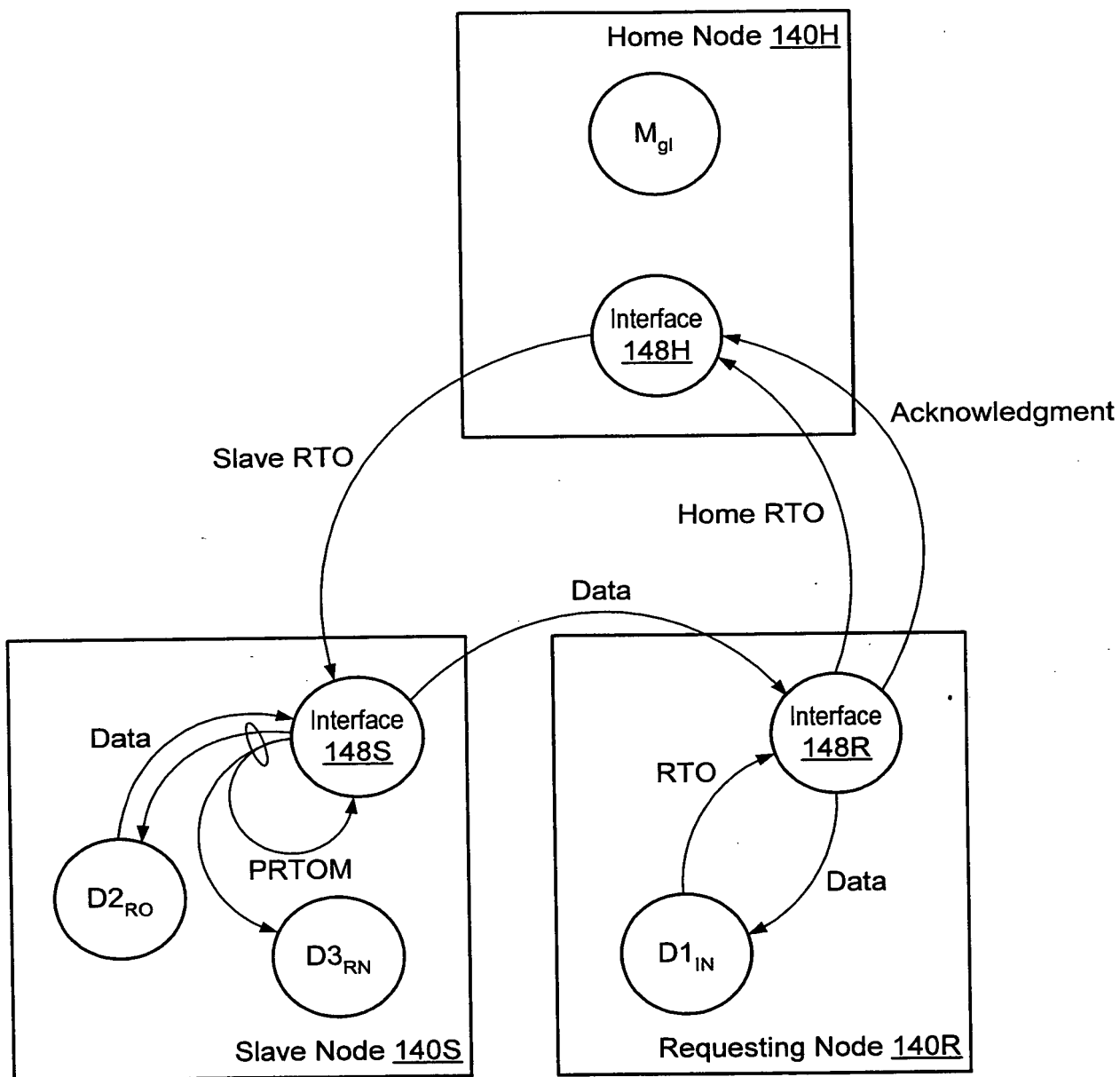


Fig. 26

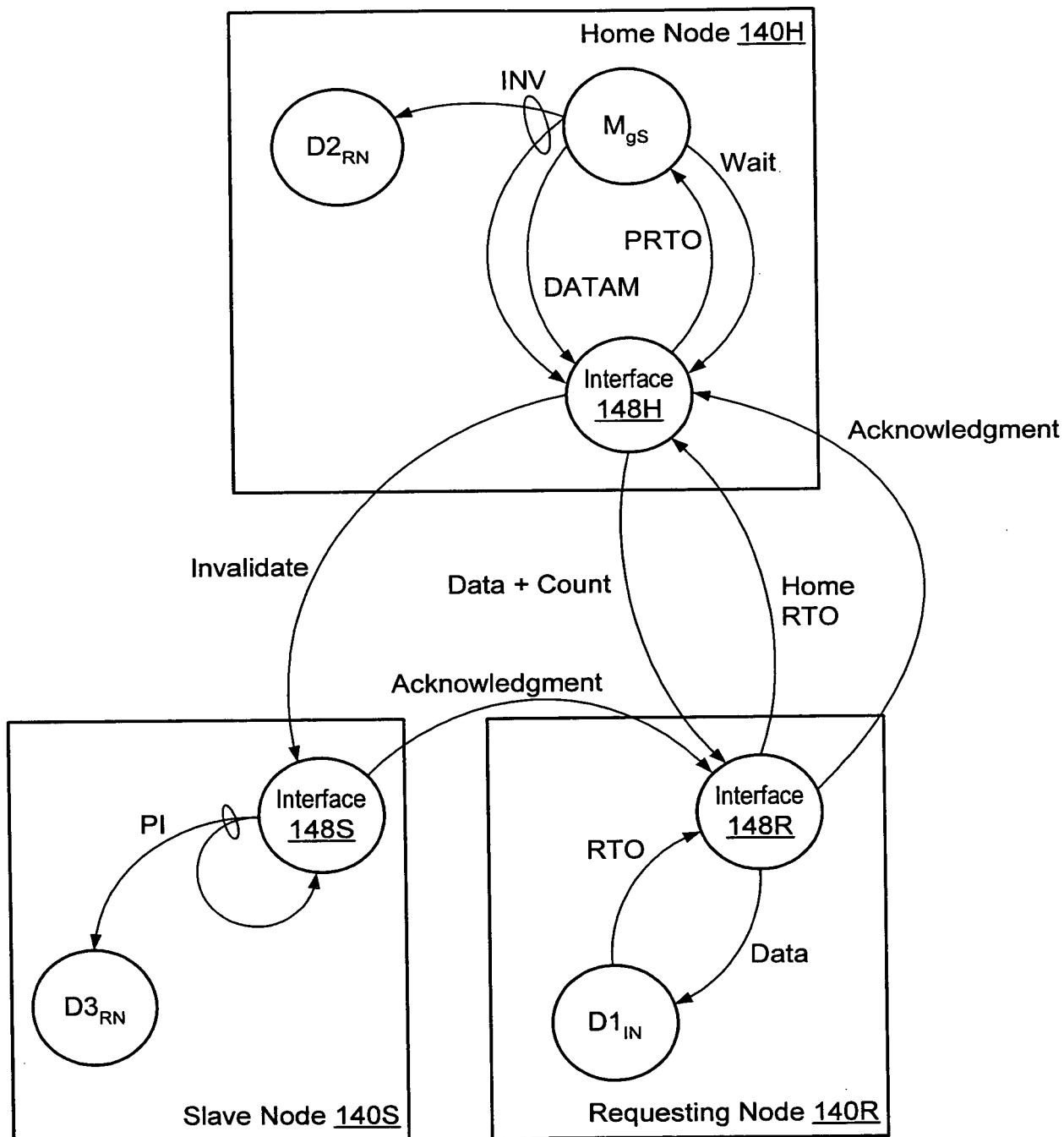


Fig. 27

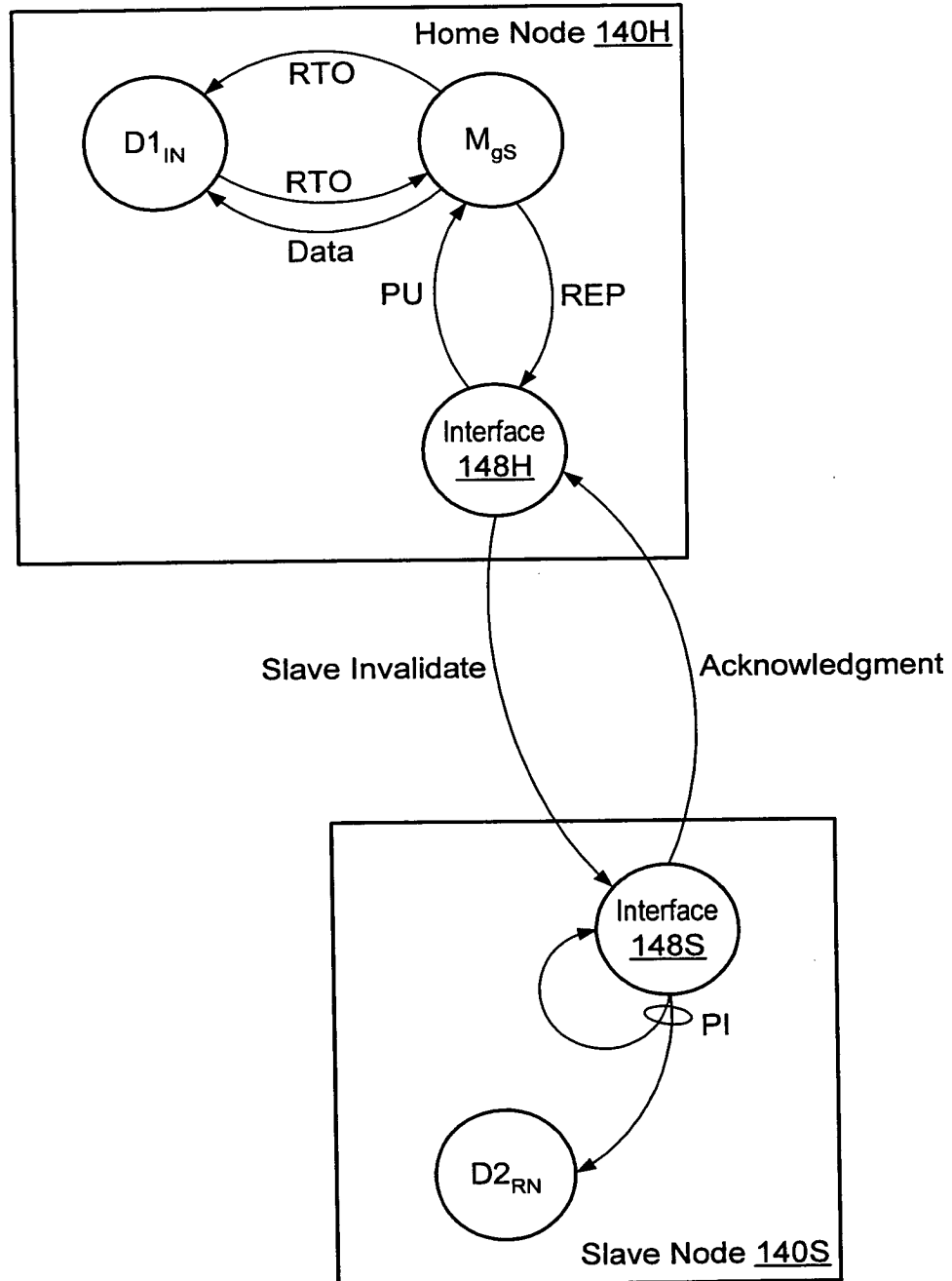


Fig. 28

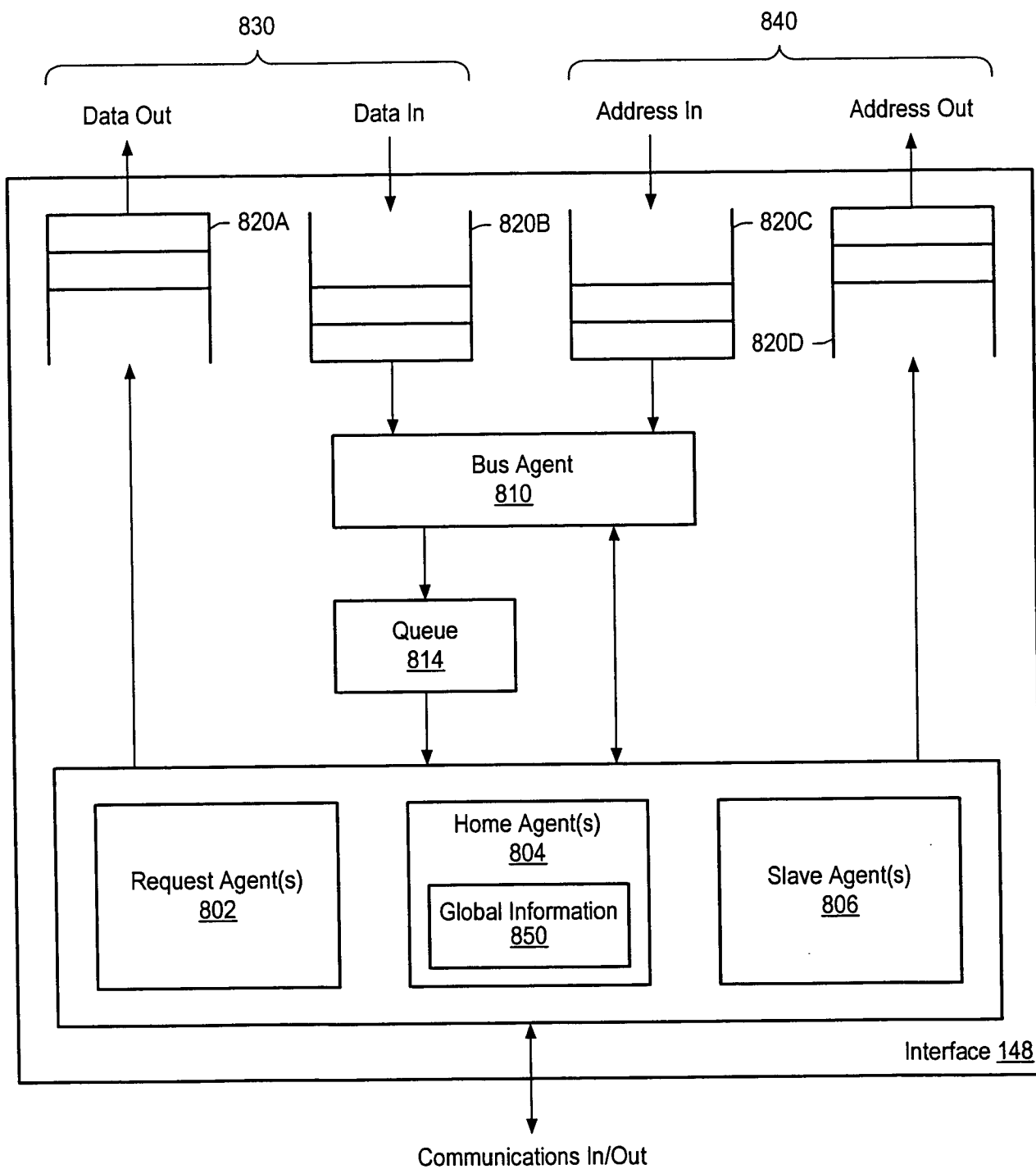


Fig. 29

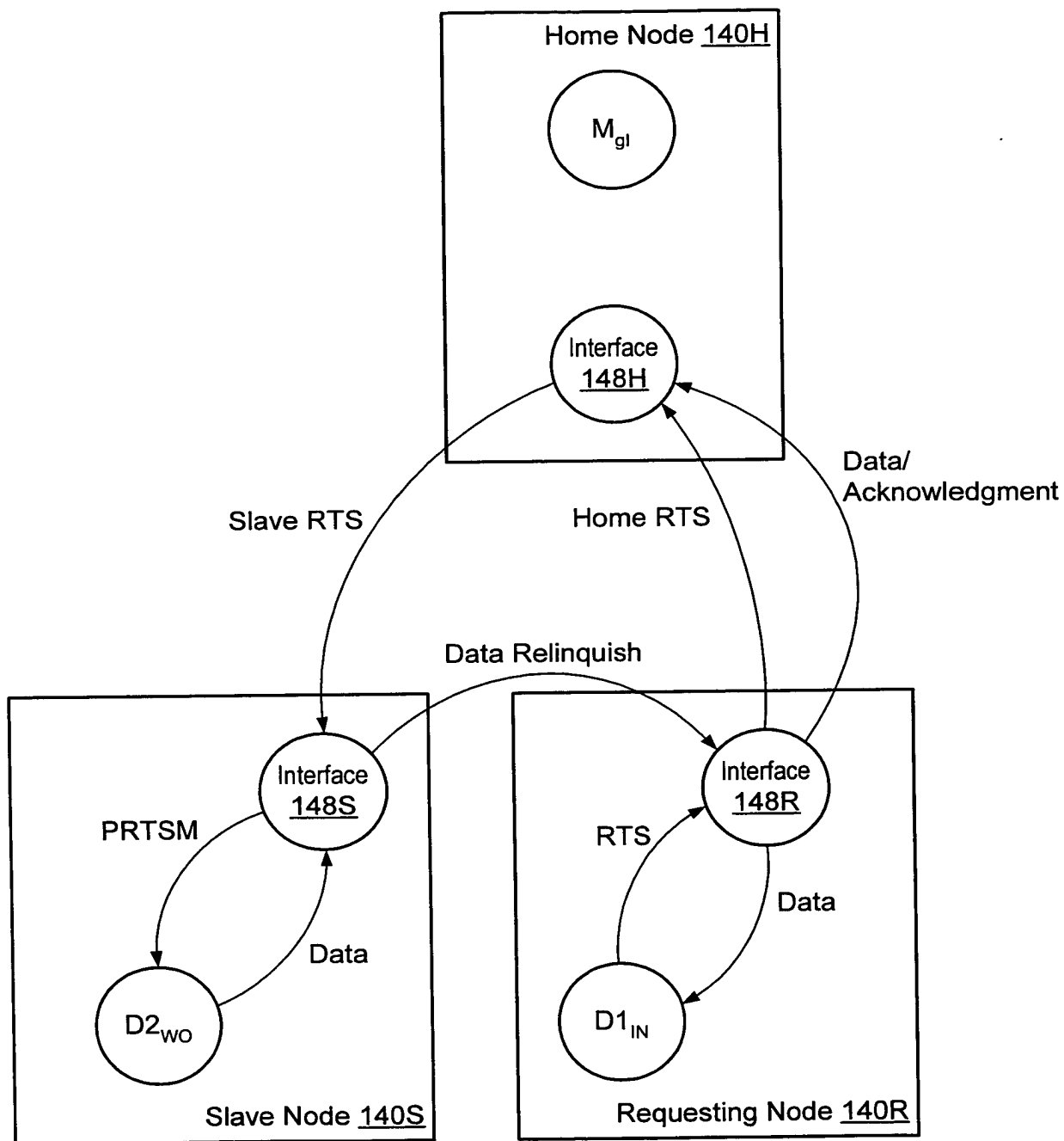


Fig. 30

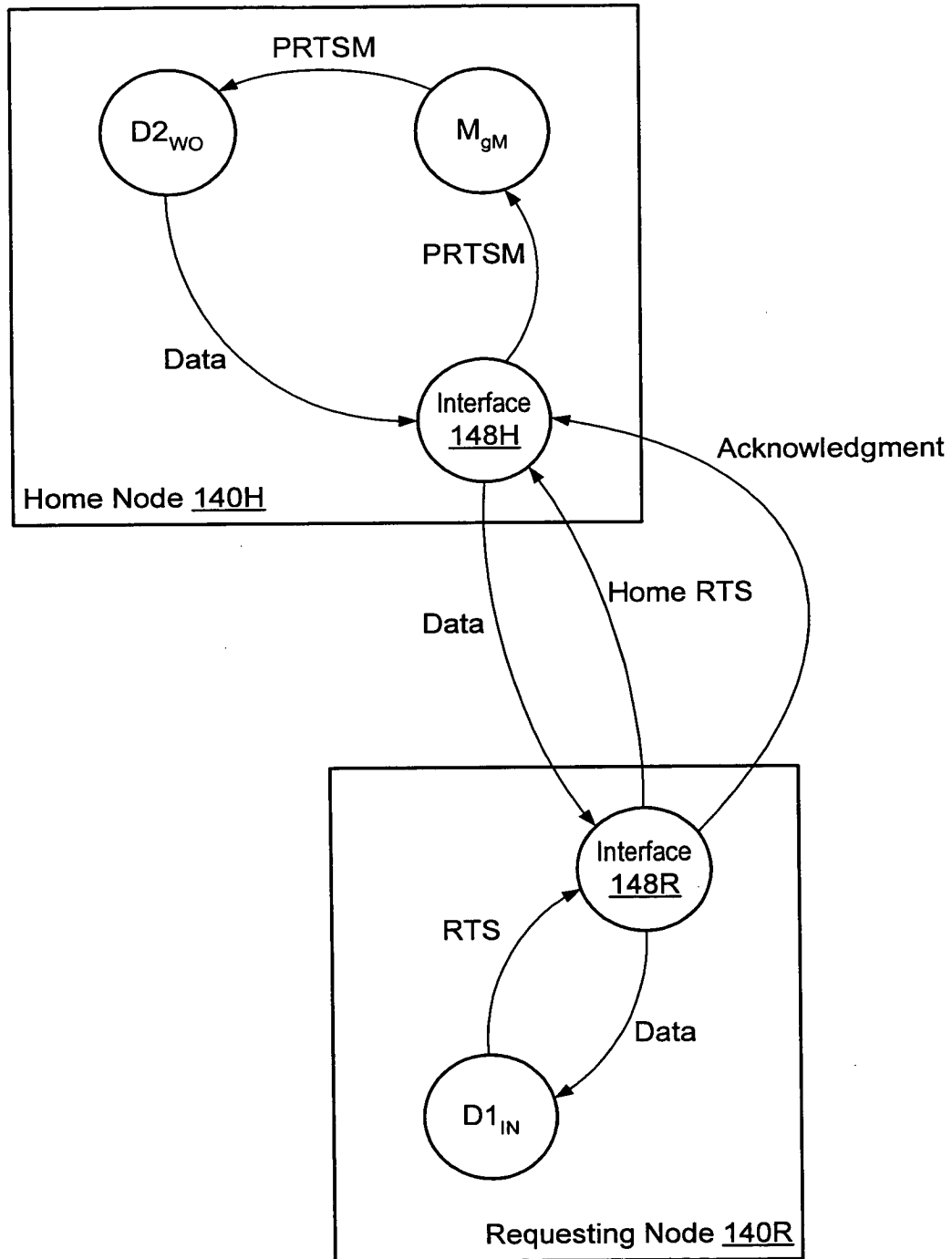


Fig. 31

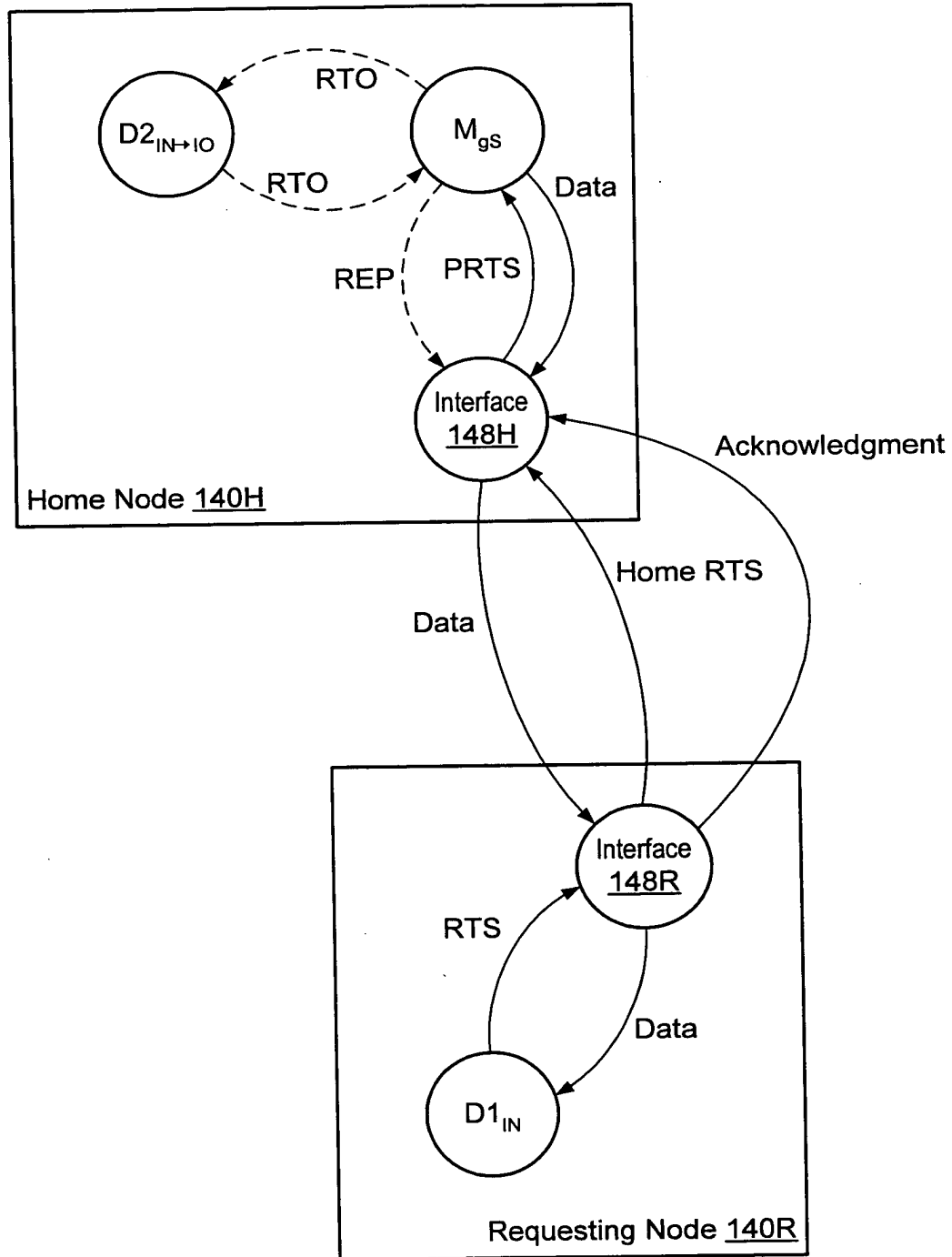
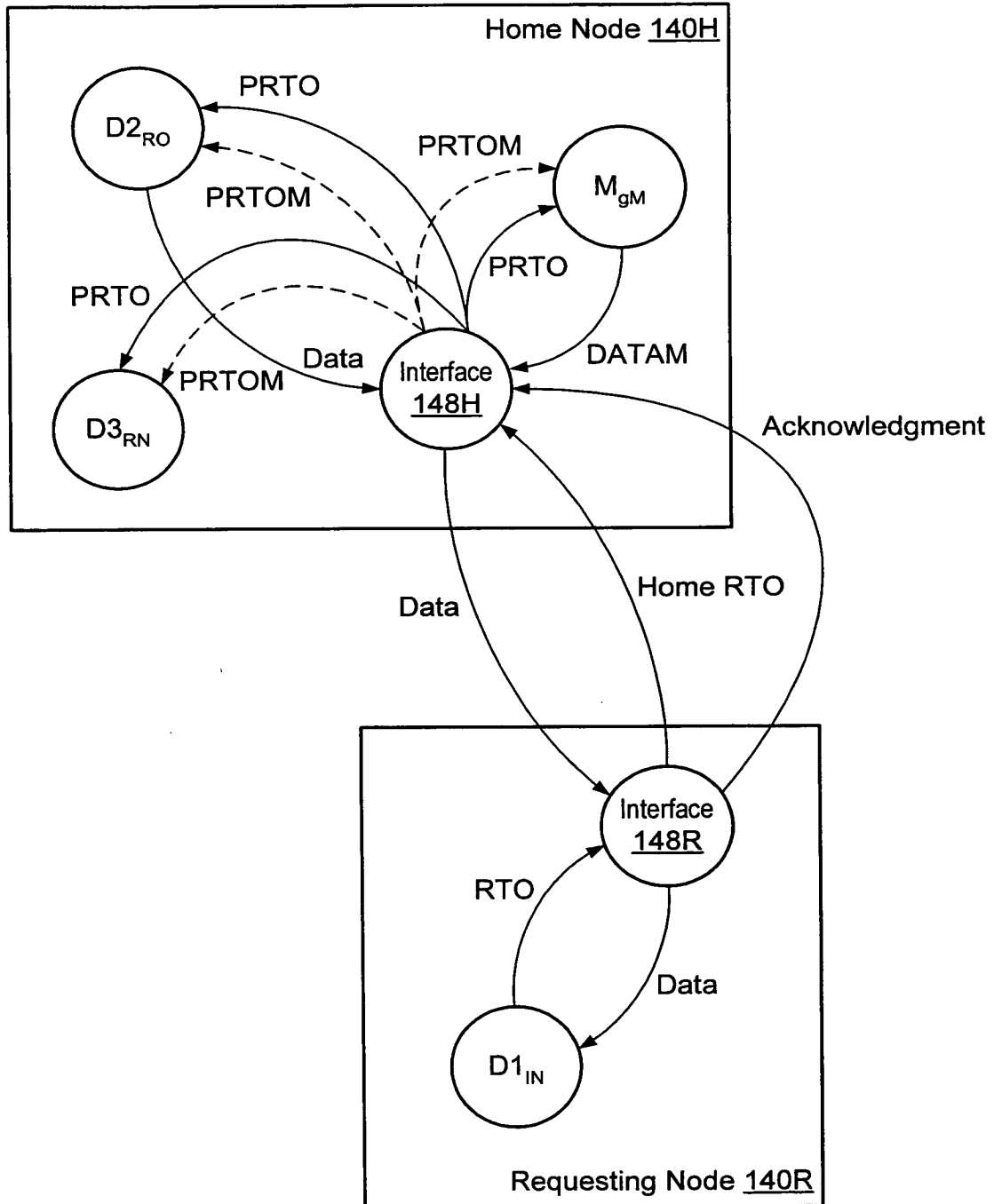


Fig. 32

*Fig. 33*

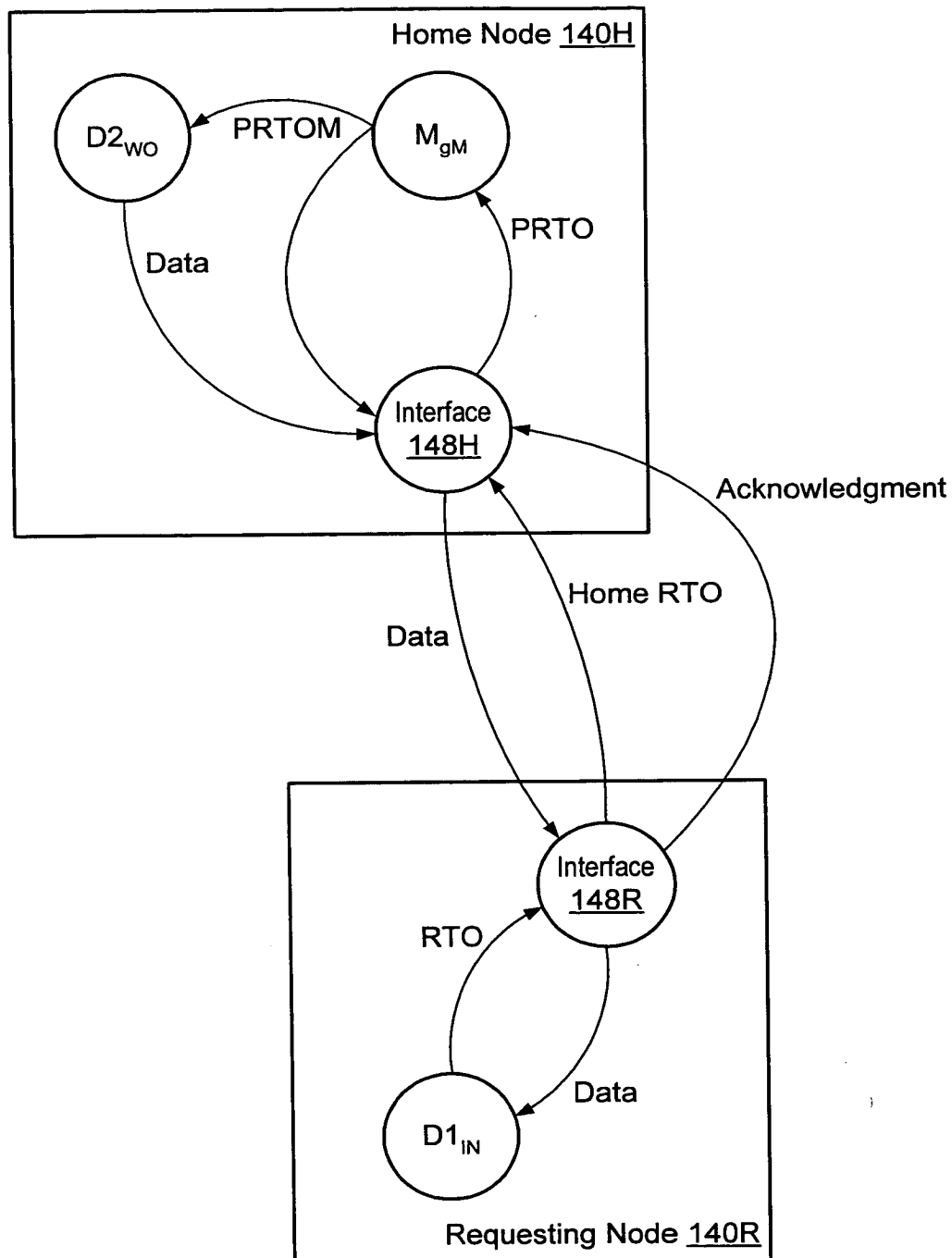


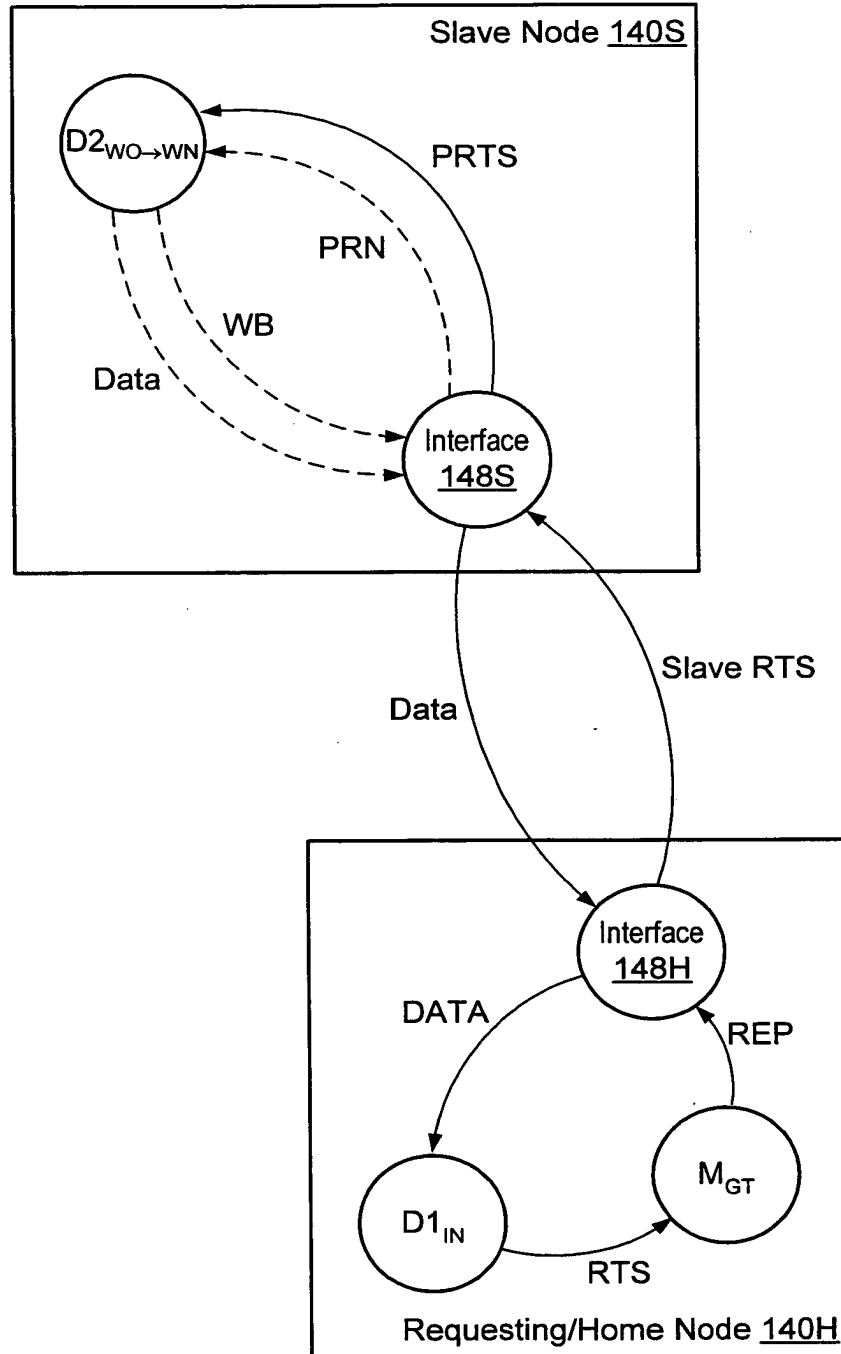
Fig. 34

| Response Info | Coherence State | Home Memory Subsystem Action |
|----------------------|------------------------|---|
| No | gM | BC Mode-- Allow owning device to respond. PTP Mode-- Forward response to owning device |
| No | gS | Send REP packet to interface if write access requested |
| No | gl | Send REP packet to interface |
| Yes | gM | Respond with copy of the requested coherency unit |

Fig. 35

| Response Info | Memory Subsystem's Action |
|----------------------|---|
| mN | Does not respond with copy of coherency unit because a cache within the node owns the coherency unit |
| mR | Does respond because memory is the owner |
| mS | Does respond to requests for shared access because memory has shared copy and no active device has ownership; does not respond to requests for write access |
| ml | Does not respond because memory's copy is invalid |

Fig. 36

*Fig. 37*

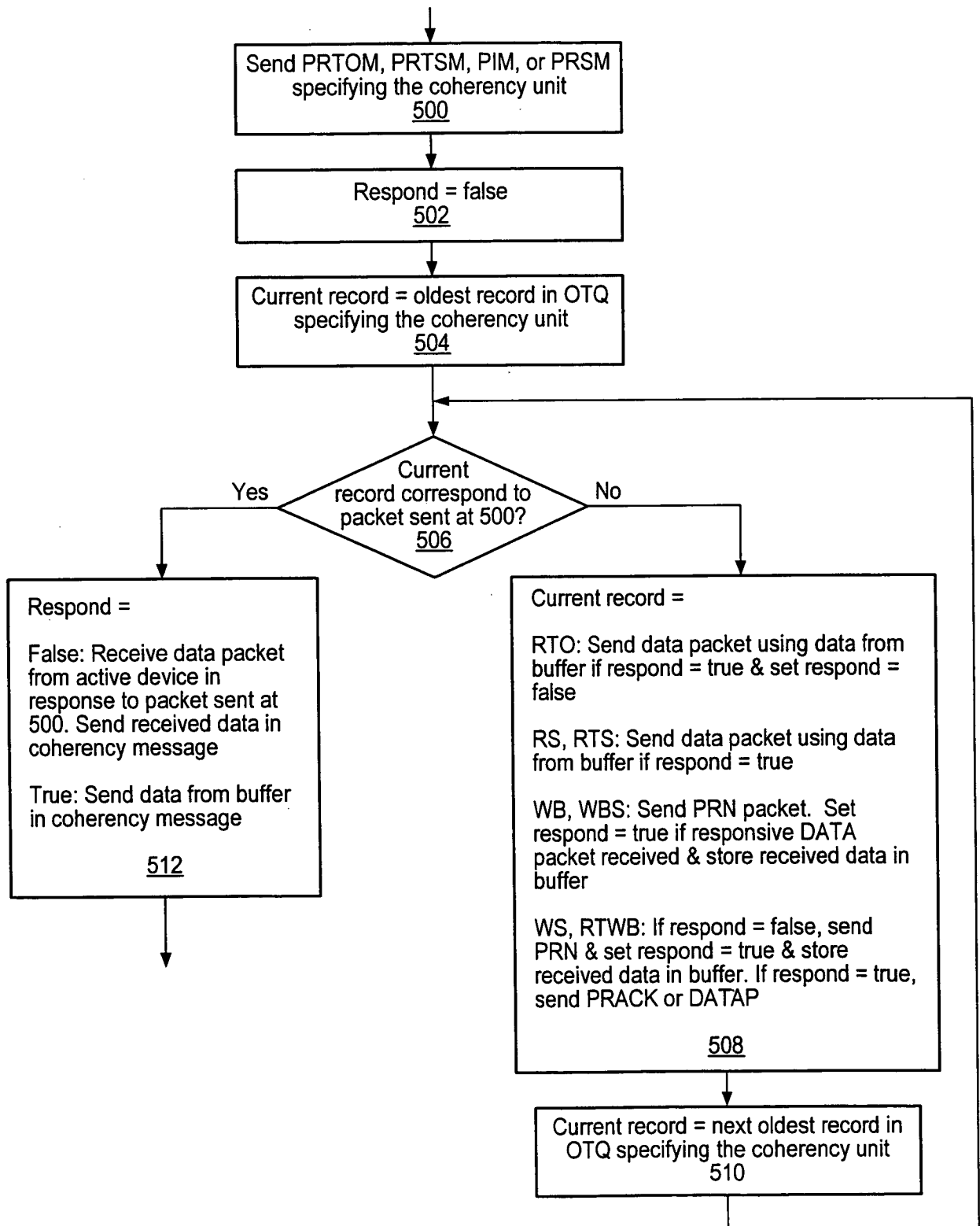


Fig. 37A

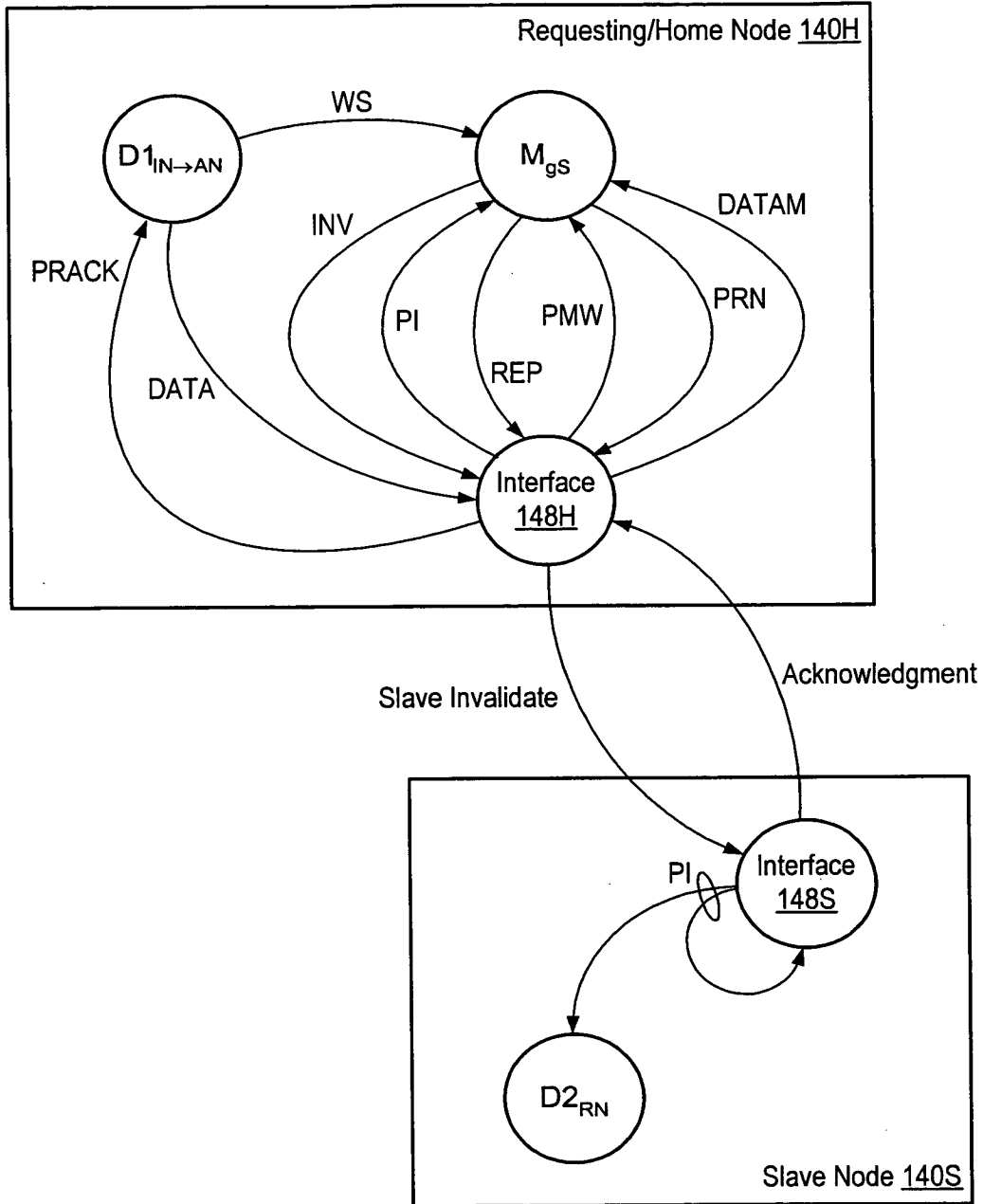


Fig. 38

| Packet Type | Full Name | Description |
|-------------|------------|--|
| RWB | Remote WB | Request sent from an active device in a multi-node system to an interface in order to initiate a WB transaction |
| RWBS | Remote WBS | Request sent from an active device in a multi-node system to an interface in order to initiate a WBS transaction |
| RWS | Remote WS | Request sent from an active device in a multi-node system to an interface in order to initiate a WS transaction |

Fig. 39

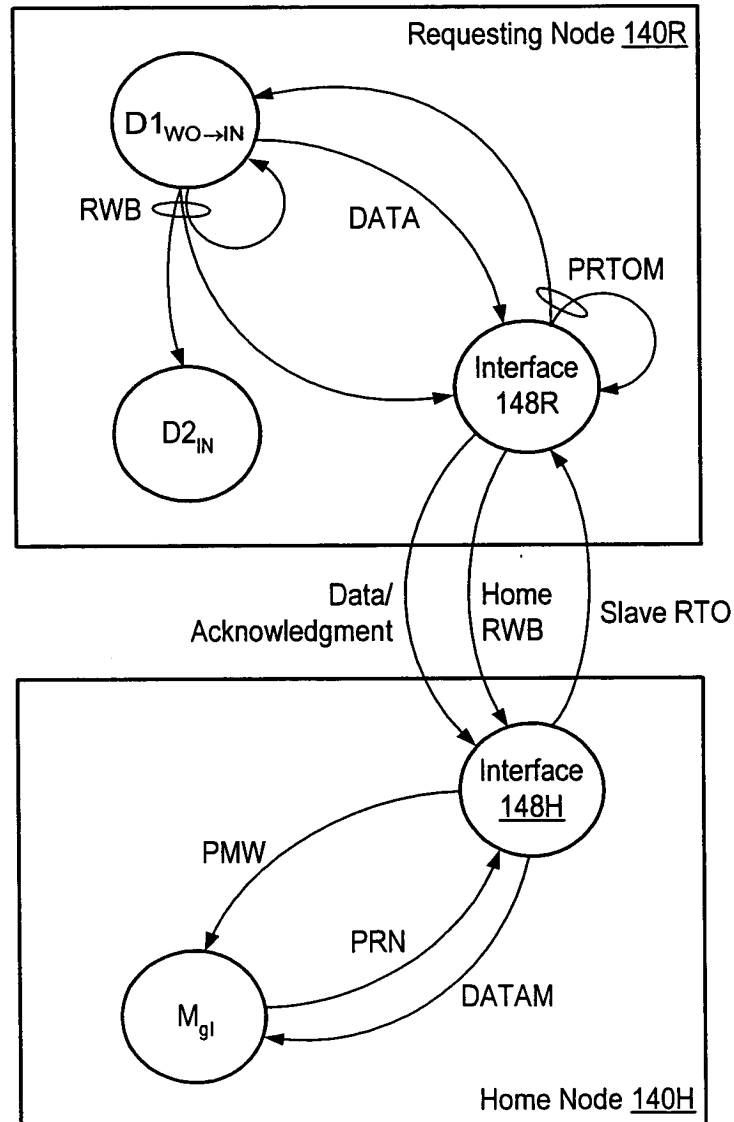


Fig. 40

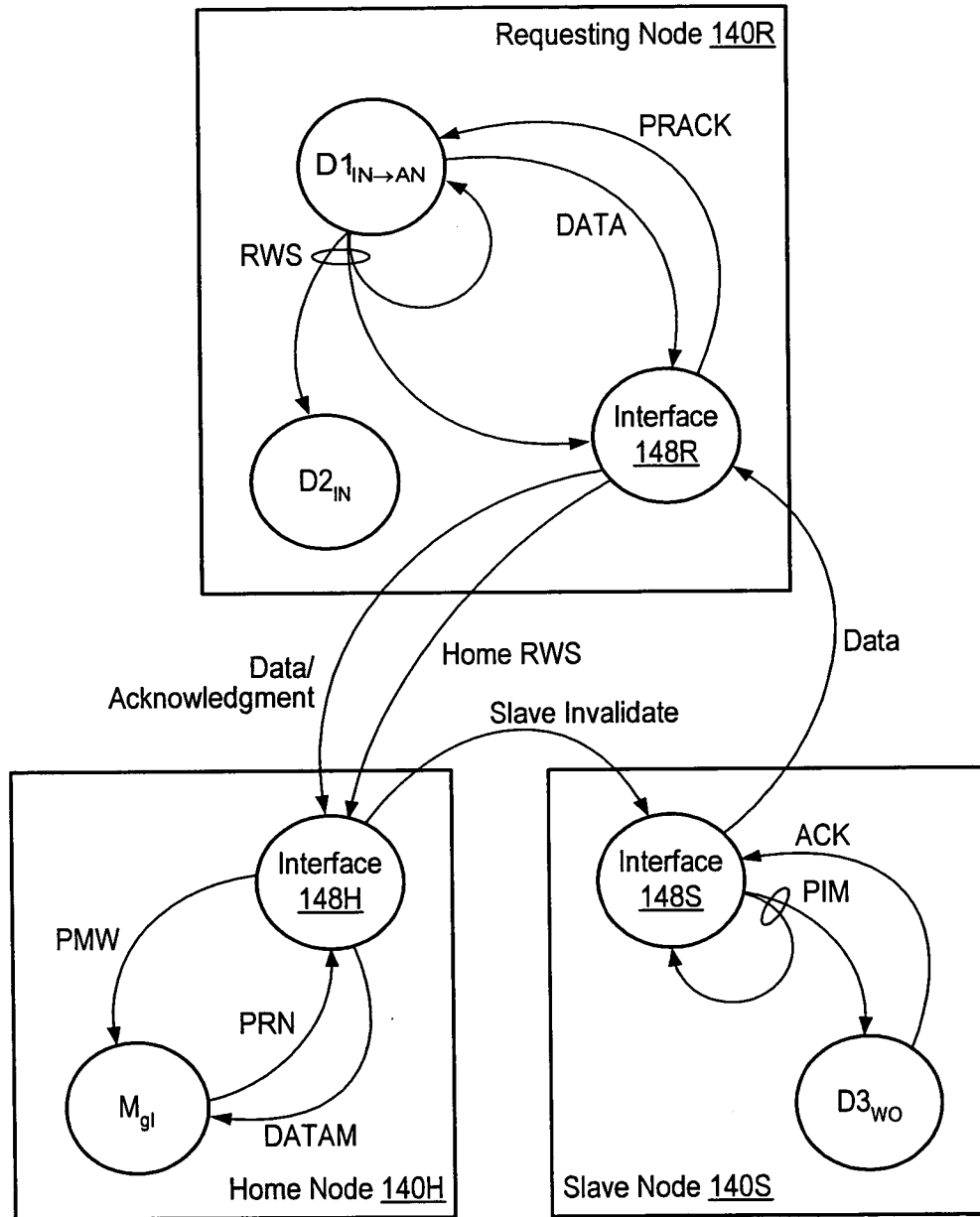


Fig. 41